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TRC Environmental Consultants, Inc.
East Hartford, CT

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16. ABSTRACT

This report summarizes the results of a comprehensive evaluation of eight air quality models applicable to complex terrain. Seven of the models are "Gaussian" and one is "numerical." The models are evaluated with data obtained from two field measurements programs. The Cinder Cone Butte data base is for tracers released upwind of a dense sampler network for a limited number of hours. The Westvaco data base contains a year of routine hourly SO_2 measurements for an 11 station network. The report includes numerous tabulations of each model's performance in terms of statistical measures of performance recommended by the American Meteorological Society.

The purpose of the report is two-fold. First, it serves to document for the models considered, and similar models, their relative performance. Second, it provides the basis for a peer scientific review of the models. To stay within the spirit of this latter purpose, the report is limited to a factual presentation of information and performance statistics. No attempt is made to interpret the statistics or to provide direction to the reader, lest reviewers might be biased.

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SECTION 1

INTRODUCTION

The Environmental Protection Agency (EPA) is currently involved in a study to evaluate the performance of air quality dispersion models using statistical measures recommended by the American Meteorological Society. It was EPA's intent, as published in a notice in the March 1980 Federal Register, to provide organizations the opportunity to submit dispersion models for possible inclusion in the next revision of EPA's "Guideline on Air Quality Models".[1] EPA has undertaken a systematic evaluation of these models to decide in an objective manner which models should be included in the guideline and what recommendations should be made concerning the use of these dispersion models for regulatory applications. Several categories of models have been identified including models designed for complex terrain situations. TRC, working under contract to EPA, has assembled the aerometric data sets needed for model input and comparison, set up and run the complex terrain models and produced statistics relating observed and predicted air quality.

In September 1980 the American Meteorological Society (AMS), as a professional organization with expertise in atmospheric dispersion, organized a workshop (sponsored by EPA) to consider the issue of model performance evaluation. The 1980 workshop held at Woods Hole, Massachusetts, produced a report entitled "Judging Air Quality Model Performance."[2] This report contains recommended statistical procedures for comparing observed air quality with model predictions. The procedures recommended by the Woods Hole workshop provided the basis for the statistical comparisons presented in this report. TRC has performed similar studies for EPA to evaluate eight rural models[3,4] and six urban models[5]. On the basis of these studies and subsequent comments by the AMS reviewers, a trimmed-down list of statistical comparisons are provided for the complex terrain model evaluation.

In Section 2 the eight complex terrain models are described. The models include COMPLEX I, COMPLEX II, COMPLEX/PFM, 4141, PLUME5, RTDM, SHORTZ and IMPACT. The distinguishing technical features of these models, as run for the current evaluation, are described. Also, the procedures for implementing and testing the models and the unique input data requirements are presented.

The above models have been evaluated with data obtained from two field measurements programs which were carried out in complex terrain environments. The Cinder Cone Butte tracer data base provides air quality measurements with good spatial resolution (94 samplers) for a limited number of study hours (104). The Westvaco data base comes from a rigorous routine-measurements program one year of hourly data at 11 stations, for this study designed for regulatory considerations. These data sets, along with supplemental data, are described in Section 3.

In Section 4 the statistical approach is described. The sets of observed and predicted concentration values have been paired in a variety of ways to provide statistical model performance comparisons that reflect either high concentration values or all concentration values, with and without pairing according to time and space.

The results of this study are presented in Section 5. The tables of statistical comparisons based on the performance measures recommended by the AMS workshop are presented in this section for all eight models run with both data bases.

Three appendices provide additional information. Appendix A is a copy of the TRC document "Test Run Package: Description of the Models 'As Run' for Complex Terrain Model Evaluation" which describes test run procedures, model-by-model code modifications and listings of model input options selected by the model developers for this evaluation. Appendices B and C contain statistical tables for Westvaco and Cinder Cone Butte, respectively. These tables provide statistical results by model for each type of data comparison and for subsets by meteorology and source-receptor geometry.

SECTION 2

COMPLEX TERRAIN MODELS

The following eight complex terrain air quality models have been evaluated by TRC using the performance measures recommended by the American Meteorological Society:

- COMPLEX I
- COMPLEX II
- COMPLEX/PFM
- 4141
- PLUME5
- RTDM
- SHORTZ
- IMPACT

Of these eight models, seven are based on the Gaussian plume assumptions, while IMPACT is a numerical grid model. Specific methods for prescribing plume rise, transport and dispersion differ from model to model, but all of the models require similar basic user-supplied input data describing source characteristics, receptor locations, and representative meteorology. IMPACT generally needs more detailed meteorological input data than the Gaussian models.

DOCUMENTATION

Computer code and documentation for each of the complex terrain models are available to the public. COMPLEX I and COMPLEX II were developed by EPA and are described as screening techiques for applications in complex terrain environments [27]. Currently no user guides exist for these models. Documentation exists as part of the FORTRAN code and also in the MPTER user's manual[6] from which these two models were adapted. COMPLEX/PFM[7] was developed for EPA by Environmental Research & Technology, Inc. (ERT) as an adaptation of COMPLEX I with provisions for either COMPLEX I, COMPLEX II or potential flow model (PFM) calculations. The model 3141/4141[8] was developed by Enviroplan, originally as a modified version of CRSTER[9], and more recently as a modified version of MPTER. The 4141 option of the MPTER version was employed in this study. PLUME5[10] was developed by Pacific Gas and Electric, and the Rough Terrain Diffusion Model (RTDM)[11] was developed by ERT. SHORTZ[12] was developed by the H.E. Cramer Company. An updated version of SHORTZ which includes an algorithm to account for vertical wind direction shear[13] was used in this study. Two versions of IMPACT (Integrated Model for Plumes and Atmospheric Chemistry in Complex Terrain)[14,15] were submitted to EPA. The authors of both versions were contacted and they agreed that very little difference between results from the two versions was likely, at least for the purposes of this evaluation. Therefore, the Fabrick and Haas version was selected for this evaluation.

TECHNICAL FEATURES

Distinguishing features of the complex terrain models as run for the current evaluation are listed in Table 2-1. The information listed in Table 2-1 is presented by model and then by generalized modules including transport, dispersion/stability, plume rise/terrain impaction and limits to vertical mixing. These modules represent physical processes that the models are attempting to simulate. It is not the intent here to fully describe each of the complex terrain models, but rather to list briefly the primary technical features that distinguish one model from another. In-depth technical discussions of each model can be obtained from the appropriate model-user guides. The reader is encouraged to refer to the users manuals for technical details and references.

As part of the model evaluation process, test run packages were prepared and supplied to the model developers for their review and concurrence. A description of this procedure can be found in Appendix A which contains a copy of one of the test run package documents[16]. This document also summarizes the model code modifications made by TRC and describes the input options selected by the model developers for each model and data base. Modifications to the models were needed to adapt each model to the EPA UNIVAC computer, to adapt particular models to accept the source-receptor inventories and to format the output of calculated concentrations for input to the statistics system.

It is also noted that ERT (RTDM) and H. E. Cramer Co. (SHORTZ) previously had the opportunity to test their models using at least portions of the data sets selected for this evaluation. Both data sets were previously used by ERT, while only the Westvaco data set was used by the H. E. Cramer Co. According to the developers, the models were not modified based on these evaluations. However, these developers could select model options and model inputs to optimize model performance, based on previous experience.

MODEL INPUT DATA REQUIREMENTS

All of the complex terrain models require basic user-supplied input data describing source characteristics, receptor locations and representative meteorology. Other model inputs control options for data input/output and technical considerations.

Source Data

Each of the models requires that the fixed geographic and geometric characteristics of each source be specified by the model user. The location is generally specified in Cartesian or polar coordinates except for the IMPACT model which requires horizontal source locations to be specified as central cell positions within a Cartesian three-dimensional grid. The stack base elevation, physical stack height, and stack gas exit diameter are fixed variables also required by each of the models.

Pollutant emission rate, stack gas exit velocity and stack gas temperature are generally needed by the complex terrain models in the calculation of plume rise and ambient concentration. The temporal variation of these parameters is available as one-hour averages in the Cinder Cone Butte and Westvaco data bases. Plume rise was not a factor in the Cinder Cone Butte tracer study (passive releases) and therefore stack velocity and temperature are not available. Many of the models had to be modified to accept hourly varying source data.

TABLE 2-1 DISTINGUISHING FEATURES OF THE COMPLEX TERRAIN MODELS AS RUN FOR THE CURRENT EVALUATION

COMPLEX I

Transport

- Wind speed as input at release height
- Wind direction as input

Dispersion/Stability

- Turner stability categories (class 7 treated as class 6)
- Gaussian vertical distribution using rural, (P-G) σ_z
- 22.5 horizontal sector averaging
- Buoyancy induced vertical dispersion

Plume Rise/Terrain Impaction

- Terrain adjustments = .5, .5, .5, .5, .0, .0 for Stability A-F
- Minimum terrain approach = 10m
- Briggs final plume rise, including momentum rise
- Stack tip downwash for non-passive plumes

Limits to Vertical Mixing

- Full reflection at ground and mixing height
- Uniform vertical mixing beyond where σ_z = 1.6 x mixing height

COMPLEX II

Transport

- Wind speed as input at release height
- Wind direction as input

Dispersion/Stability

- Turner stability categories (class 7 treated as class 6)
- Bivariate Gaussian distribution (PGT σ_y and σ_z)
- Buoyancy induced dispersion

(Continued on next page)

TABLE 2-1 (Continued)

Plume Rise/Terrain Impaction

- Terrain adjustments = .5, .5, .5, .5, .0, .0 for stability A-F
- Minimum terrain approach = 10m
- Briggs final plume rise including momentum rise
- Stack-tip downwash for non-passive plumes
- Linear concentrations drop-off with height above plume centerline

Limits to Vertical Mixing

- Full reflection from ground and mixing height
- Uniform vertical mixing beyond where σ_z = 1.6 x mixing height

COMPLEX/PFM

Transport

- Wind speed as input at release height for COMPLEX I/II calculations
- Wind speed adjusted in potential flow model (PFM) calculations as a function of streamline deformation
- Wind direction as input

Dispersion/Stability

- Turner stability categories (class 7 treated as class 6)
- COMPLEX I (22.5 sector averaging) for D, E or F stability when plume is below dividing streamline height
- COMPLEX II for A, B, or C stability
- PFM (adjusted PGT σ_y and σ_z) for D, E or F stability when plume is above dividing streamline height
- Buoyancy induced vertical dispersion

Plume Rise/Terrain Impaction

- COMPLEX I/II terrain adjustments = .5, .5, .5, .5, .0, .0 for stability A-F
- COMPLEX I/II minimum terrain approach = 10m
- PFM plume height reduced for deformed streamlines
- Modified Briggs layered plume rise
- Stack tip downwash for non passive plumes

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TABLE 2-1 (Continued)

Limits to Vertical Mixing

- Full reflection at ground and mixing height
- Uniform vertical mixing beyond where σ_z = 1.6 x mixing height

4141

Transport

- Wind speed as input at release height
- Wind direction as input

Dispersion/Stability

- Turner stability categories (class G treated as class F)
- Bivariate Gaussian distribution (PGT σ_z and time-enhanced PGT σ_y)
- Buoyancy induced dispersion

Plume Rise/Terrain Impaction

- Terrain adjustments = .5, .5, .5, .5, .25, .25
- Briggs transitional plume rise

Limits to Vertical Mixing

- Full reflection at ground and mixing height
- Uniform vertical mixing beyond where σ_z = 1.6 x mixing height

IMPACT

Transport

- Input wind speed and direction at multiple sites extrapolated and interpolated to 3-dimensional grid cells
- Divergence-free wind field created

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TABLE 2-1 (Continued)

Dispersion/Stability

- Finite difference solution to diffusion equation
- Diffusivities from DEPICT model using Smith's (empirical) formulations

Plume Rise/Terrain Impaction

- Plume/terrain approach controlled by wind and diffusivity fields
- Briggs layered plume rise including penetration of stable layers

Limits to Vertical Mixing

- Temperature stratifications incorporated into wind and diffusion fields

PLUME5

Transport

- Wind speed as input at release height
- Wind direction as input

Dispersion/Stability

- Stability categories from horizontal turbulence intensity (σ_θ) and time of day (class A treated as class B; class G treated as class F)
- Bivariate Gaussian distribution (PGT σ_y and σ_z)
- Enhanced horizontal dispersion due to vertical wind directional shear
- Buoyancy induced dispersion

Plume Rise/Terrain Impaction

- Conservative modification to one-half plume height concept
- Briggs final plume rise with determination of stable layer penetration

Limits to Vertical Mixing

- Full reflection at ground and mixing height
- Uniform vertical mixing beyond where σ_z = 1.6 x mixing height

(Continued on next page)

TABLE 2-1 (Continued)

RTDM

Transport

- Wind speed extrapolated from release height to plume height
- Wind direction as input

Dispersion/Stability

- Stability categories from vertical turbulence intensity (σ_ϕ) measured at Westvaco
- Bivariate Gaussian distribution (dispersion coefficients from measured turbulence data)
- Buoyancy induced dispersion
- Enhanced horizontal dispersion for plumes rising through a shearing wind

Plume Rise/Terrain Impaction

- Terrain impingement for stable plumes below critical height
- Half height correction for neutral or unstable conditions and stable conditions when plume exceeds critical height
- Briggs transitional plume rise; hourly potential temperature gradients for stable plume rise
- Stack tip downwash for non-passive plumes

Limits to Vertical Mixing

- Partial terrain reflection; full mixing lid reflection
- Mixing height adjustment for plume path
- Unlimited mixing height for stable conditions

SHORTZ

Transport

- Wind speed extrapolated from release height to plume height
- Wind direction as input

(Continued on next page)

TABLE 2-1 (Continued)

Dispersion/Stability

- Bivariate Gaussian distribution (Cramer dispersion coefficients from measured turbulence data)
- Cramer technique for enhanced horizontal dispersion due to vertical wind direction shear
- Buoyancy induced dispersion

Plume Rise/Terrain Impaction

- Terrain impingement within the mixing layer
- Modified Briggs final plume rise; hourly potential temperature gradient for stable plume rise
- Stack tip downwash for non-passive plumes

Limits to Vertical Mixing

- Full reflection at ground and mixing height
- Uniform mixing beyond where reflection terms (i=3) exceed exp(-10)
- Mixing height constant above sea level, for determination of plume penetration
- Minimum actual mixing depth of H = u x 200 meters (u = wind speed) for Westvaco; Height where vertical intensity of turbulence drops below 0.01 radians for Cinder Cone Butte.

Receptor Data

Each of the complex terrain models produces calculated concentrations at multiple receptor locations. In all of the models except IMPACT, discrete receptors at arbitrary locations are defined in Cartesian or polar coordinates. The IMPACT model defines receptor locations internally as the central cell position within each of the 3-dimensional grid "boxes." All of the complex terrain models require receptor elevations above a local reference plane.

Meteorological Data

Meteorological data are used by the models to calculate transport, dispersion, plume rise and limited mixing between sources and receptors. The complex terrain models expect a broad range of meteorological parameters, as summarized in Table 2-2. The IMPACT model allows data from one or multiple meteorological towers to be internally pre-processed into 3-dimensional fields for input to the grid model. The other complex terrain models are exercised with meteorological data from one "representative" station. The representative input data sets used in this evaluation consist of a composite of parameters measured at more than one site. A detailed description appears in Section 3.

TABLE 2-2

COMPOSITE OF ALL METEOROLOGICAL PARAMETERS EXPECTED BY THE COMPLEX TERRAIN MODELS TO EXERCISE VARIOUS MODEL FUNCTIONS

Model Function			
Transport	Dispersion (Stability)	Plume Rise	Limited Mixing
Wind Speed	P-G Stability	Temperature	Mixing Height
Wind Direction	σ_θ or I_y	Wind Speed	
Anemometer Height	σ_e or I_z	dT/dZ	
Power Law Exponents	Wind Direction Shear	P-G Stability	
Temperature and Wind Speed for Froude Number and Critical Height			

Some of the complex terrain models contain preprocessor programs that must be exercised in order to obtain a complete set of model-consistent meteorological input data. CRSMET, the CRSTER preprocessor, is used to generate hourly Pasquill-Gifford stability categories from on-site wind speeds and National Weather Service (NWS) cloud observations for input to COMPLEX I, COMPLEX II, COMPLEX/PFM and 4141. RTDM uses this data for the Cinder Cone Butte application. Westvaco mixing heights from CRSMET are used by COMPLEX I, COMPLEX II and 4141. CONVRT, the preprocessor for PLUME5, is used to generate stability class from horizontal turbulence measurements. Westvaco mixing heights are also generated from CONVRT. METZ is the SHORTZ preprocessor which is used to generate mixing heights for Westvaco. The PROFILE preprocessor to COMPLEX/PFM is used with the Westvaco data set to develop vertical profiles of temperature and wind speed which are subsequently needed by the model for calculations of Froude number and critical streamline height. TRC developed preprocessors for providing profiles of meteorological data needed as input to the IMPACT model.

Description of specific model input data for both Westvaco and Cinder Cone Butte are provided in Section 3.

SECTION 3

DATA BASES FOR COMPLEX TERRAIN MODEL EVALUATION

The complex terrain models have been evaluated with data obtained from two field measurements programs which were carried out in complex terrain environments. The Cinder Cone Butte tracer data base provides air quality measurements with good spatial resolution for a limited number of study hours. The Westvaco data base, containing a small number of stations for an extended period of continuous monitoring, results from a rigorous routine-measurements program designed for developing a model to be applied in a regulatory setting. Terrain at the Westvaco-Luke Mill is steep, uneven and rugged; Cinder Cone Butte is a simple, isolated terrain feature.

Both data bases were originally obtained for what might be called research objectives, or diagnostic model evaluation. As a result, there existed an overabundance of meteorological data which was trimmed down to enable operational evaluation of the models. Trimmed down or "modeler's data bases" were recommended for use in this evaluation so that a common set of input data could be used in as many models as possible. The intention was to reduce uncertainties in model predictions resulting from minor differences in input data, and hence allow relative differences between the models to be evaluated strictly on the basis of technical merit. Of course, model input data requirements do differ somewhat from model to model. These model requirements were accounted for in the preparation of test run and final input data sets as described in this section.

CINDER CONE BUTTE DATA BASE

The Cinder Cone Butte experiment represents the first major component of the EPA-sponsored Complex Terrain Model Development Program.[17,18,19] The broad objective of the experiment was to determine the behavior and impact of an elevated plume in the vicinity of an isolated elevated-terrain feature. During the period between October 16, 1980 and November 12, 1980, 18 multi-hour dual tracer gas experiments were conducted during primarily stable atmospheric conditions. The periods when tracer tests were conducted are listed in Table 3-1.

As can be seen from Figure 3-1, Cinder Cone Butte is a roughly axisymetric, 100 meter high isolated hill. The hill is located in southeastern Idaho about 50 m south-southeast of Boise. The surrounding Snake River Basin is a broad, nearly level plain.

TABLE 3-1

PERIODS WHEN TRACER TESTS WERE CONDUCTED DURING THE CINDER CONE BUTTE EXPERIMENT[17]

Experiment No.	1980 Date	Experiment Hours (PST)	Hours	Typical Stability
201	10/16	1700-2300	6	E
202	10/17	1700-2300	6	E
203	10/20	0000-0800	8	E-F
204	10/21	0000-0800	8	E-F
205	10/23	0000-0800	8	E
206	10/24	0000-0800	8	E
207	10/25	0000-0800	8	E-F
208	10/27	1700-0100	7	E-F
209	10/28	1700-0100	7	F
210	10/30	0000-0740	7	E-F
211	10/31	0000-0800	8	E-F
213	11/04	0000-0800	8	E-F
214	11/05	0200-1000	8	E-F
215	11/06	0000-0600	6	E-F
216	11/09	0000-0700	7	E-F
217	11/10	0200-1000	8	E-F
218	11/12	0200-1000	8	E

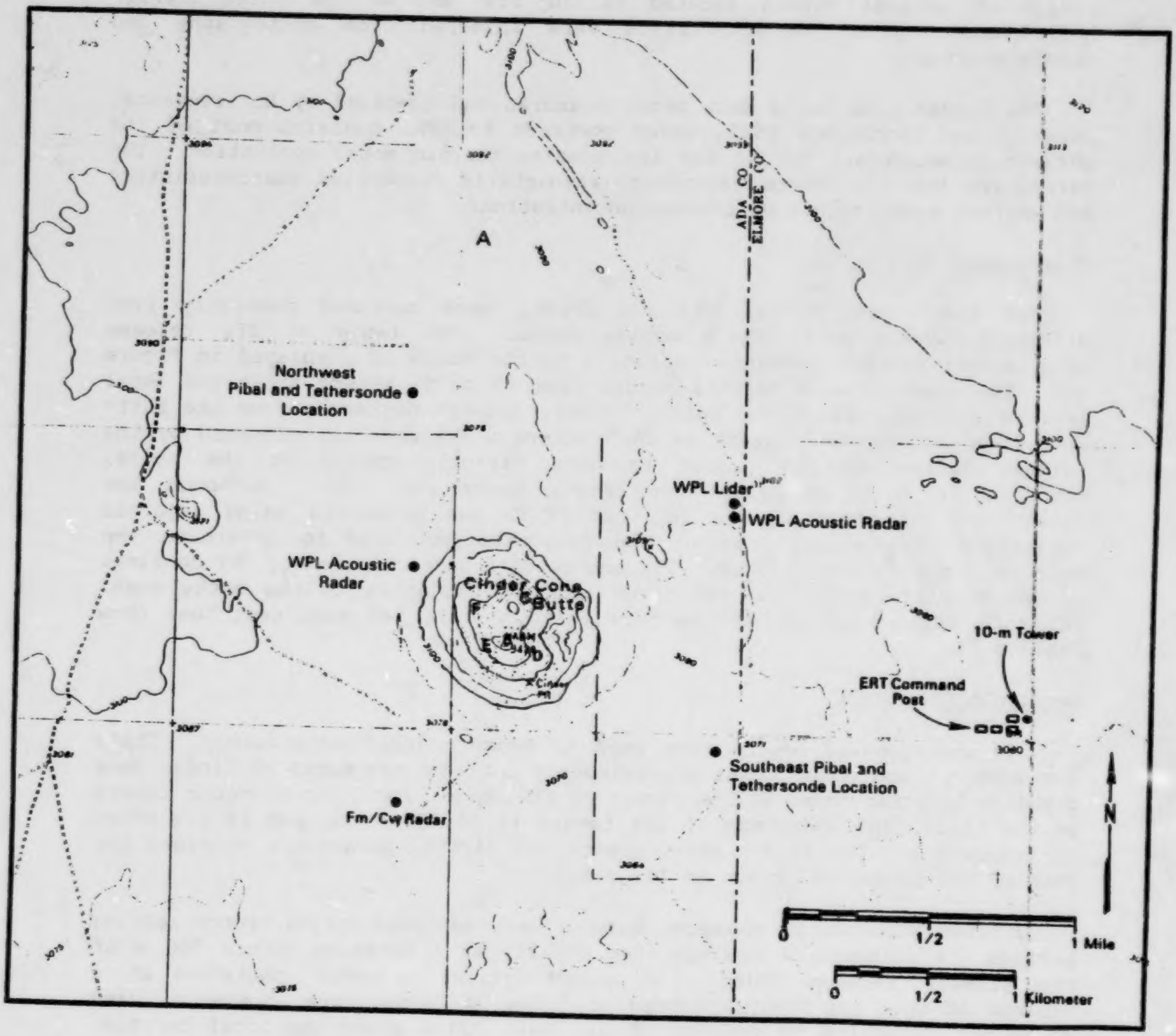
A
Northwest
Pibal and Tethersonde
Location
WPL Acoustic
Radar
Cinder Cone
Butte
F
C
E
B
D
WPL Lidar
WPL Acoustic Radar
ADA CO
ELMORE CO
10-m Tower
ERT Command
Post
Southeast Pibal and
Tethersonde Location
Fm/Cw Radar
N
0
1/2
1 Mile
0
1/2
1 Kilometer
3100
3090
3080
3070

Figure 3-1. Cinder Cone Butte field experiment layout. A is the 150 m tower; B is the 30 m tower; C, D, E, F are 10 m towers(Ref. No. 17).

Ground-level measurements of two tracer gases, sulfur hexafluoride (SF_6) and freon (CF_3Br), were conducted during testing periods. Each test persisted for approximately eight hours with tracer gas releases occurring during five or six of these hours. Of the 111 test hours, 104 were used in this model evaluation. Tracer measurements were accompanied by an extensive collection of meteorological measurements taken on multiple levels of several towers located in the area and on the butte itself. Additionally, plume characteristics were inferred from photography and remote sensing.

The Cinder Cone Butte data base, measured and compiled by Environmental Research and Technology (ERT) under contract to EPA, contains most of the parameters which are needed for the complex terrain model evaluation. The parameters describe source emissions, atmospheric dispersion characteristics and ambient measurements of tracer concentrations.

Source Data

The two tracer gases, SF_6 and CF_3Br, were released passively from different levels utilizing a mobile crane. The range of SF_6 release heights and release distances relative to the butte is displayed in Figure 3-2. The crane release heights ranged from 15 to 57 meters above the local terrain at the base of the butte. Tracer release distances from the butte center ranged from 540 meters to 1420 meters. The mobility afforded by the release system enabled tracer releases directly upwind of the butte, producing a high number of successful hours per test. Although the variability of gas flow for SF_6 and CF_3Br was monitored using separate rotameters, the weight loss of the cylinders was used to determine the emission rate of each tracer. The source data base compiled by ERT consists of the vertical and horizontal crane location (relative to the butte peak) for each release period and average emission rate for each test hour (see Table 3-2).

Meteorological Data

Six instrumented towers were used to measure local meteorology. These included: a 150 meter tower approximately 2 kilometers north of Cinder Cone Butte; a 30 meter tower at the summit of the butte; and four 10 meter towers on the hill. The locations of the towers (A, B, C, D, E, and F) are shown in Figure 3-1. The direct measurements and derived parameters obtained for each of the towers are given in Table 3-3.

Various atmospheric sounding devices were employed during tracer testing periods. A tethersonde was operated usually at a location within 700 m of the primary release point. An ascent-descent sequence conducted at a minimum of once per hour generated profiles of temperature, pressure, wind speed and direction to heights of at least 200 m above the local terrain. When high wind speeds precluded tethersonde operation, profiles were obtained from minisonde flights. Hourly wind profiles were also derived from pilot balloons (pibals). Additionally a frequency-modulated, continuous-wave (FM/CW) radar, and two monostatic acoustic radars were operated near the butte.

The meteorological tower data has been assembled by ERT and currently resides on magnetic tape. Corrections were made by ERT to known errors in the wind speed and wind direction measurements. Temperature corrections were not made, given that the results of two independent audits were

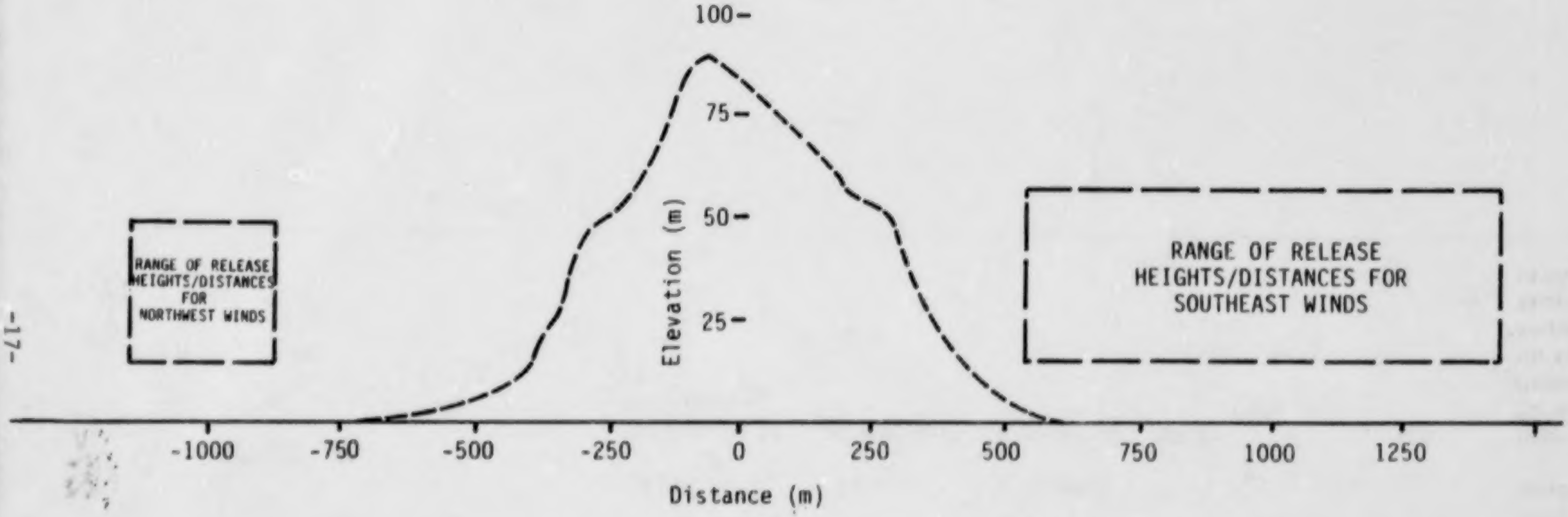

Figure 3-2. Cinder Cone Butte vertical cross section from northwest (315°) to southeast (135°).

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TABLE 3-2

UNITS AND AVERAGING TIMES CORRESPONDING TO MEASURED VARIABLES REPORTED IN THE CINDER CONE BUTTE DATA BASE

Source			Meteorological			Tracer		
Parameter	Units	Averaging Time	Parameter	Units	Averaging Time	Parameter	Units	Averaging Time
emission rate	gms^{-1}	hourly	wind speed	ms^{-1}	5 minutes	SF_6 concentration	ppt	hourly, 10 minutes depending on mode of sequential sampling used
			wind direction	degrees	5 minutes			
			temperature	°C	5 minutes			
			radiation	ly min^{-1}	5 minutes			
			intensity of turbulence	% radians	5 minutes	CF_3Br	ppt	hourly, 10 minutes depending on mode of sequential sampling used

TABLE 3-3

CINDER CONE BUTTE TOWER INSTRUMENTATION AND MEASURES[17]

Site	Instruments*	Direct Measures	Derived Measures
Tower A			
Level 0 (1 m)	Pyranometer	Insolation	
	Net radiometer	Net radiation	
Level 1 (2 m)	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	Cup and vane	UX, VX	SP, DR
	RTD	T	
Level 2 (10 m)	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	Cup and vane	UX, VX, U, $\sigma\theta$	SP, DR
	RTD	ΔT (10 m - 2 m)	T
	Fast bead thermistor	T, σ_T	
Level 3 (20 m)	RTD	T	
Level 4 (40 m)	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	RTD	ΔT (40 m - 2 m)	T
Level 5 (60 m)	RTD	T	
Level 6 (80 m)	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	RTD	ΔT (80 m - 2 m)	T
Level 7 (100 m)	RTD	T	
Level 8 (150 m)	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	Cup and vane	UX, VX	SP, DR
	RTD	ΔT (150 m - 2 m)	T
	Fast bead thermistor	T, σ_T	
Tower B			
2 m	Triaxial props	U, V, W, IX, IY, IZ	WS, WD
	RTD	T	

* All temperature sensors were mounted in aspirated radiation shields; an RTD is a Resistance Thermometric Device.

(continued on next page)

TABLE 3-3 (Continued)

CINDER CONE BUTTE TOWER INSTRUMENTATION AND MEASURES[17]

Site	Instruments*	Direct Measures	Derived Measures
Tower B (Continued)			
10 m	Triaxial props Cup and vane RTD	U, V, W, IX, IY, IZ UX, VX ΔT	WS, WD SP, DR T
30 m	Triaxial props Cup and vane RTD	U, V, W, IX, IY, IZ UX VX ΔT	WS, WD SP, DR T
Towers C, D, E, F			
2 m	Triaxial props RTD	U, V, W, IX, IY, IZ T	WS, WD
10 m	Triaxial props Cup and vane RTD	U, V, W, IX, IY, IZ UX, VX ΔT	WS, WD SP, DR T

* All temperature sensors were mounted in aspirated radiation shields; an RTD is a Resistance Thermometric Device.

Key

U: westerly component of wind measured by east-west oriented propeller
V: southerly component of wind measured by north-south oriented propeller
W: vertical component of wind measured by vertically oriented propeller
SP: horizontal wind speed measured by cup anemometer
DR: horizontal wind direction measured by vane
$\sigma\theta$: standard deviation of horizontal wind direction calculated from vane output
UX: easterly component of wind calculated from the cup and vane outputs
VX: southerly component of wind calculated from the cup and vane outputs
WS: horizontal wind speed calculated from U and V
WD: horizontal wind direction calculated from U and V
IX: downwind intensity of turbulence
IY: crosswind intensity of turbulence (IY approximates $\sigma\theta$ for small horizontal wind deviations)
IZ: vertical intensity of turbulence (IZ approximates $\sigma\phi$ for small vertical wind deviations)
T: temperature (resistance thermometric device)
σT: standard deviation of temperature
ΔT: temperature difference

inconsistent. Turbulence intensity data were also left uncorrected although errors in these data are known to exist due to the response characteristics of the propeller sensors. Other identified errors that remain in the data base are due to the effects of the wake of one instrument on another and the effects of tower wakes on turbulence measurements and wind direction. Users of this data set have been advised by ERT to give precedence where possible to wind measurements from instruments that are more clearly out of wakes. The meteorological tower data has been recorded on tape as five-minute averages for the variables listed in Table 3-2. Data from pibal, mini-sonde, and tethersonde flights are available on a separate magnetic tape.

Tracer Data

Tracer samples were obtained with approximately 90 battery-operated samplers which were sequentially operated for either 10 minute or 1 hour periods. Figure 3-3 shows the locations of the 70 fixed samplers and the 10 movable samplers. The movable samplers were deployed either on the northwest or southeast side of the hill, depending on the prevailing wind direction. For a typical test, 60 of these 80 sites provided 1-hour average samples and 20 were designed to obtain 10-minute average samples. An additional 10 samplers were used: on masts for measuring plume reflection from the ground; for measuring background concentrations; and as collocated samplers for quality assurance purposes.

Bag samples were assayed for SF_6 and CF_3Br concentrations using gas chromatography. After all bags were analyzed, a data base consisting of approximately 14,000 tracer concentration measurements representing the entire experiment was assembled and recorded on magnetic tape. For each 10-minute and 1-hour assayed sample, the experiment number, sample identification, sampling start time, sampling end time, SF_6 concentration and CF_3Br concentration are stored on the data tape (see Table 3-2).

Data Selected for Model Input

A modeler's data base (MDB) was prepared by ERT from the archive of Cinder Cone Butte data. This MDB contains hourly averages of tracer release information, ambient tracer concentrations and meteorological parameters for each of the 111 test hours in which tracer gas was released. Data needed by the models and for the evaluation were selected from the MDB. Supplemental data were also obtained to meet the needs of each of the complex terrain models. These data are described below.

Tracer Release Information

The MDB contains tracer release information for 111 test hours representing 17 different experiments. Freon gas was released along with SF_6 for nine of the experiments. Only the SF_6 releases were modeled in this evaluation, since the SF_6 data had been shown to be of higher quality. The tracer release information included:

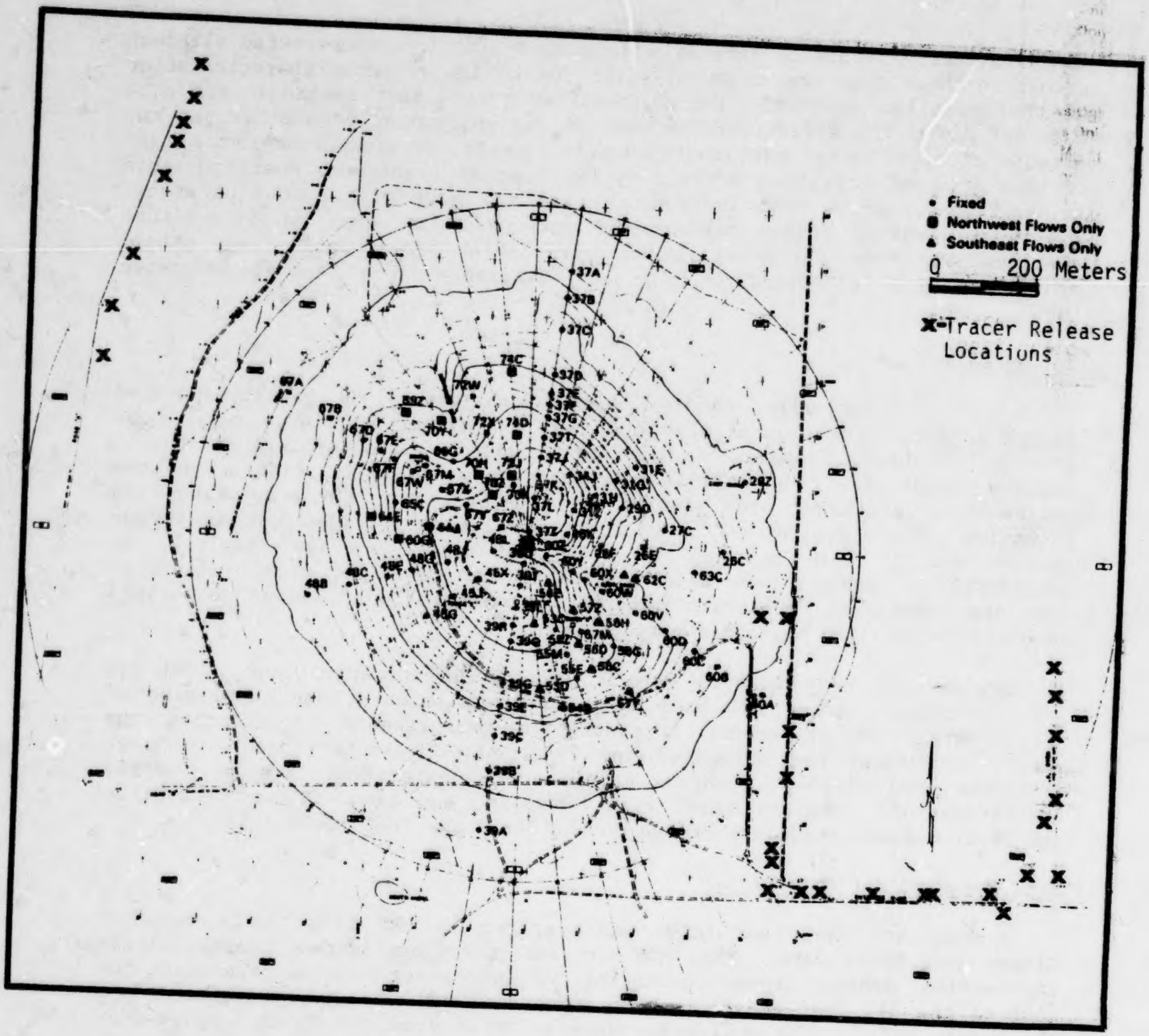

• Fixed
■ Northwest Flows Only
▲ Southeast Flows Only
0 200 Meters
X–Tracer Release Locations
37A
37B
37C
78C
37D
67A
67B
67D
67E
89Z
70W
72X
74D
37G
86G
70H
28Z
31E
31G
27C
28C
63C
62C
60X
60W
60V
60D
60B
60A
39C
39B
39A
48B
48C
45X
39R
55E
55D
39E

Figure 3-3. Cinder Cone Butte tracer gas sampler locations (Ref. No. 17). Contour intervals are 5 meters.

- average release rate for the period of each release
- start and end time of each release
- location of the crane (X, Y, Z, L) relative to a local reference frame

Seven of the experiment hours were found to have release periods of less than 40 minutes. These hours were then excluded from the evaluation, since only hourly averages were to be modeled. The net result was that 104 test hours were included in the evaluation.

The model results for Cinder Cone Butte have been evaluated on the basis of relative concentration (X/Q), so emission rates were input to each model as a fixed value of 1.0 g/s. The variable tracer emission rates provided in the data base represent the average tracer release rate for the duration of each release. Some of the experiment hours used in this study had release periods of less than an hour (but greater than 40 minutes). Tracer release rates for these hours were adjusted to hourly average rates. Hourly average tracer release rates were then used to convert the hourly measured concentrations to relative concentrations.

Ambient Tracer Concentrations

Hourly average SF_6 concentrations as measured at each of up to 94 sampler locations are included in the MDB. For the purposes of this evaluation, the measured concentrations (in the units of parts per trillion) were first converted to units of g/m^3 (using hourly on-site temperature; and pressure = 905 mb), and then converted to relative concentration, X/Q (using the release-time-adjusted hourly average tracer release rates).

Meteorology

Table 3-4 summarizes the meteorological inputs to the complex terrain models for Cinder Cone Butte. The input data are primarily from the MDB, but supplemental data were used to provide other required model input data.

The MDB contains hourly averages of measured and derived meteorological parameters representative of tracer release height (which varied from experiment to experiment). ERT used a "spline under tension" method of interpolating tower measurements to release height. Wind speed and direction are provided as both scalar and vector averages. Also provided are hourly values of critical streamline height, Froude number (for the layer between 2m and 150m), and scalar average wind speeds measured at the 10m level of Tower A.

Additional meteorological data were needed for input to some of the models. Vertical profiles using on-site tower measurements of temperature and wind speed were needed by the COMPLEX/PFM model to internally calculate critical streamline height and Froude number. Hourly P-G stability categories based on the Turner method (CRSTER preprocessor) were developed from concurrent Boise National Weather Service cloud cover observations and

TABLE 3-4
SUMMARY OF CINDER CONE BUTTE METEOROLOGICAL INPUTS TO THE COMPLEX TERRAIN MODELS

Model Function	Input Parameter	CX1	CX2	PFM	M41	IMP	PL5	RTD	SHZ
		Model							
Transport	Wind Speed	U-1	U-1	U-1	U-1	U-4	U-1	U-1	U-1
	Wind Direction	Θ-1	Θ-1	Θ-1	Θ-1	Θ-2	Θ-1	Θ-1	Θ-1
	Wind Dir. Shear	NR	NR	NR	NR	NR	NR	NR	NR
	Anemometer Ht.	Z-1	Z-1	Z-1	Z-1	Z-1	Z-1	Z-1	Z-1
	Power Law Exponents	NR	NR	NR	NR	P-1	NR	NR	NR
Dispersion	Stability	S-1	S-1	S-1	S-1	S-1	S-2	S-1	NR
	Horiz. Turb.	NR	NR	NR	NR	NR	NR	I_y	I_y
	Vert. Turb.	NR	NR	NR	NR	NR	NR	I_z	I_z
Plume Rise	Temperature	NR			No Plume Rise				
	Wind Speed	NR			Calculations for				
	dT/dZ	NR			Passive Releases at				
	Stability	NR			Cinder Cone Butte				
Limited Mixing	Mixing Height	L-1	L-1	L-1	L-1	NR	L-1	L-1	L-2
Critical Height	Temperature	NR	NR	T-2	NR	NR	NR	DT-1	NR
	Wind Speed	NR	NR	U-3	NR	NR	NR	NR	NR

Key		Description
Model	CX1	COMPLEX I
	CX2	COMPLEX II
	PFM	COMPLEX/PFM
	M41	4141
	IMP	IMPACT
	PL5	PLUME5
	RTD	RTDM
	SHZ	SHORTZ
Wind Speed	U-1	Release height scalar wind speed from Modelers' Data Base (MDB)
	U-2	Release height vector wind speed from MDB
	U-3	Profile from 150 m tower
	U-4	U-1 interpolated to middle of surface grid cell (3.75 m) using P-1

(continued on next page)

TABLE 3-4 (Continued)

Wind Direction	θ-1	Release height vector wind direction from MDB
	θ-2	θ-1 minus 90° for rotated IMPACT grid
Anemometer Height	Z-1	Set to release height for each release
Power Law Exponents	P-1	Internal IMPACT values: P = .15, .17, .20, .26, .39, .48, .54 for S-1 (A-G)
Stability	S-1	P-G category from Turner method (CRSTER preprocessor) using Boise cloud data and Cinder Cone Butte 10 m wind speed
	S-2	P-G category from $\sigma\theta$ (CONVRT preprocessor) using $\sigma_v/U\text{-}2$ from MDB where σ_v is horizontal velocity turbulence at release height
Turbulence - Y	I_y	From MDB: ($\sigma_v/U\text{-}2$) at release height
Turbulence - Z	I_z	From MDB: ($\sigma_{WH}/U\text{-}2$) at release height where σ_{WH} is vertical velocity turbulence scale with Horst correction for non-cosine response
Temperature	T-1	Release height temperature from MDB
	T-2	Profile from tower
Mixing Height	L-1	Fixed at 10,000 m
	L-2	Height where tower value of $I_z \leq 0.01$ (radians)
dT/dZ	DT-1	Derived from MDB values of Froude number (2 m - 150 m), critical height, T-1, and U-1
	NR	Not required

10m wind speeds from the MDB. Except for SHORTZ, the effect of mixing height (for these predominantly night time tracer tests) was precluded through the use of a 10,000m mixing depth. SHORTZ requires mixing depth defined as the height above which the vertical turbulence intensity drops below 0.01. These heights were developed from the on-site tower data.

Plume rise calculations for Cinder Cone Butte were not needed due to the passive nature of the tracer releases.

WESTVACO-LUKE DATA BASE

Under an agreement between the Westvaco Corporation, the State of Maryland, and the U.S. EPA[20], ambient air quality and meteorological measurements were carried out near the Luke Mill in western Maryland, from December 1, 1979 through November 30, 1981. Data from these measurements are intended to assist in the development of a rough terrain diffusion model applicable in the Luke area.[21,22] The complex topography of the area is shown in Figure 3-4. Vertical cross sections of the terrain relative to the Westvaco stack are presented in Figure 3-5 to give the reader a better feel for the source-receptor geometry. As can be seen from this figure, all of the monitors to the southeast of the mill are well above the top of the stack. Most of the monitor distances from the stack range from 0.75 to 1.5 km. The only exception is the Stony Run monitor (No. 10) at 3.4 km northeast.

The effective stack height (physical height plus plume rise) will vary significantly depending on operating load and meteorology. For normal operating loads, the effective stack height can be as low as 250-300 meters for stable conditions, or strong wind, neutral conditions; and can exceed 1000 meters for light wind, unstable conditions, based on Briggs plume rise equations.

Three types of data were measured in order to characterize SO_2 emissions from the stack, atmospheric transport and dispersion, and ambient SO_2 concentrations on the elevated terrain.

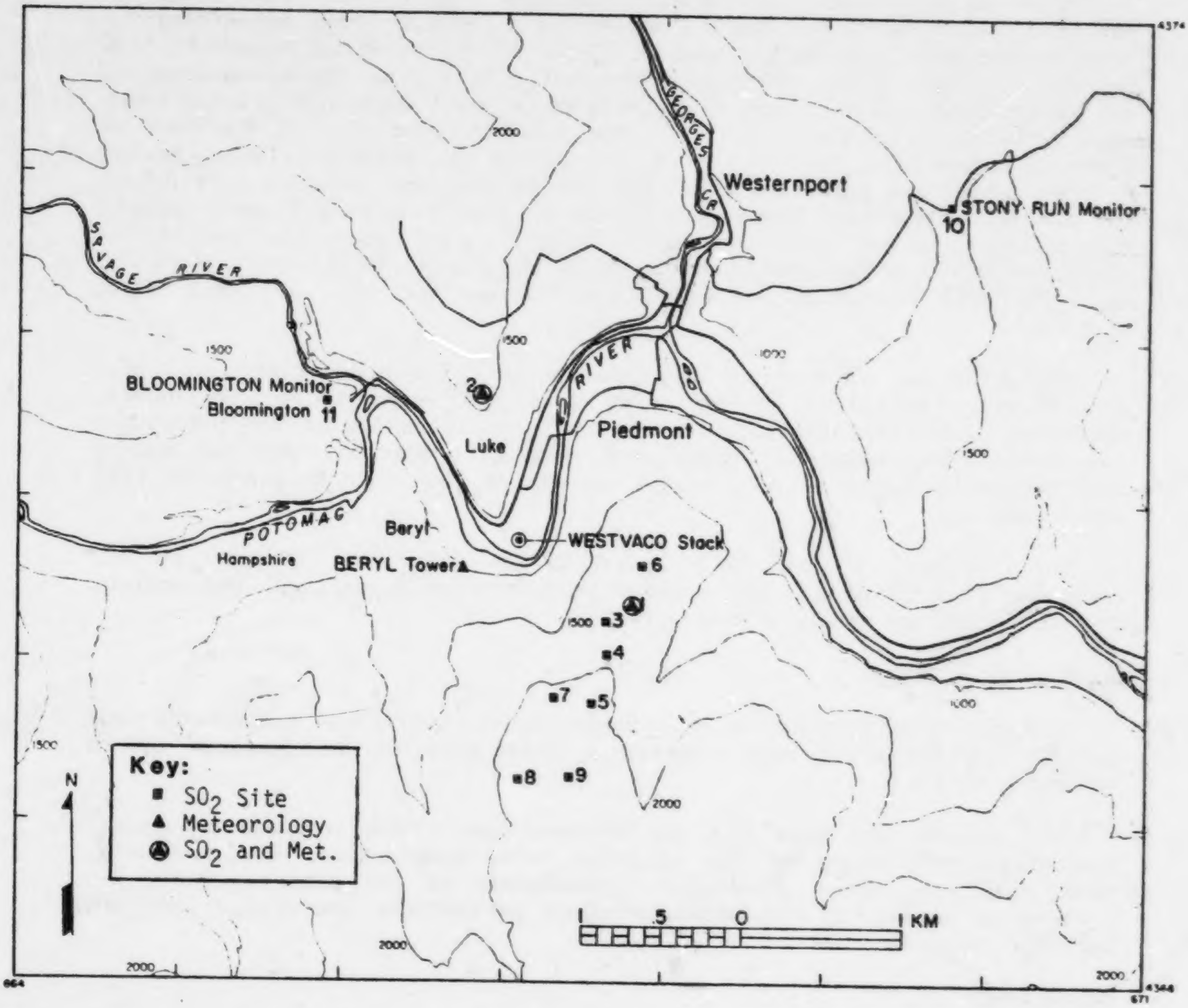
Source Data

The Luke Mill utilizes a 190 m stack to vent coal-fired emissions. Flue gas SO_2 concentration and temperature were measured continuously by an emissions monitor.

The source data base for the Westvaco-Luke stack includes sequential hourly-averaged values of SO_2 emission rate, temperature, SO_2 concentration, and steam flow (monitored continuously at the plant). Table 3-5 presents a summary of the measured stack parameters, averaging times and units of measure.

Meteorology

Three instrumented towers were used to measure meteorological parameters (see Figure 3-3). The 100 m Beryl tower had instruments mounted at 10 m and 100 m; the 30 m Luke Hill tower was instrumented at the 10 m and 30 m levels; and the 100 m Met Tower was instrumented at the 10 m, 50 m, and 100 m levels. The parameters measured at each tower are listed in Table 3-6. These include measurements of horizontal wind speed and direction, vertical wind speed, intensity of turbulence in each of the three dimensions with respect to the mean wind, vertical temperature gradient at various levels and ambient temperature. Additionally: measurements of net radiation were obtained with a radiometer at the base of the Met Tower; and an acoustic sounder, operated near the Met Tower, provided mixing depth values.



4374
2000
Westernport
GEORGES CR
STONY RUN Monitor
10
SAVAGE RIVER
RIVER
1500
1500
1000
BLOOMINGTON Monitor
Bloomington
11
2
Luke
Piedmont
1500
POTOMAC
Beryl
Hampshire
BERYL Tower
WESTVACO Stack
6
1
1500
3
4
7
5
1000
1500
8
9
2000
Key:
SO2 Site
Meteorology
SO2 and Met.
N
.5
0
1
KM
2000
2000
2000
664
4364
671

Figure 3-4. Map of the study area surrounding the Westvaco Luke Mill. Elevations are in feet above mean sea level (MSL) and the contour interval is 500 feet (Ref. No. 21).

37

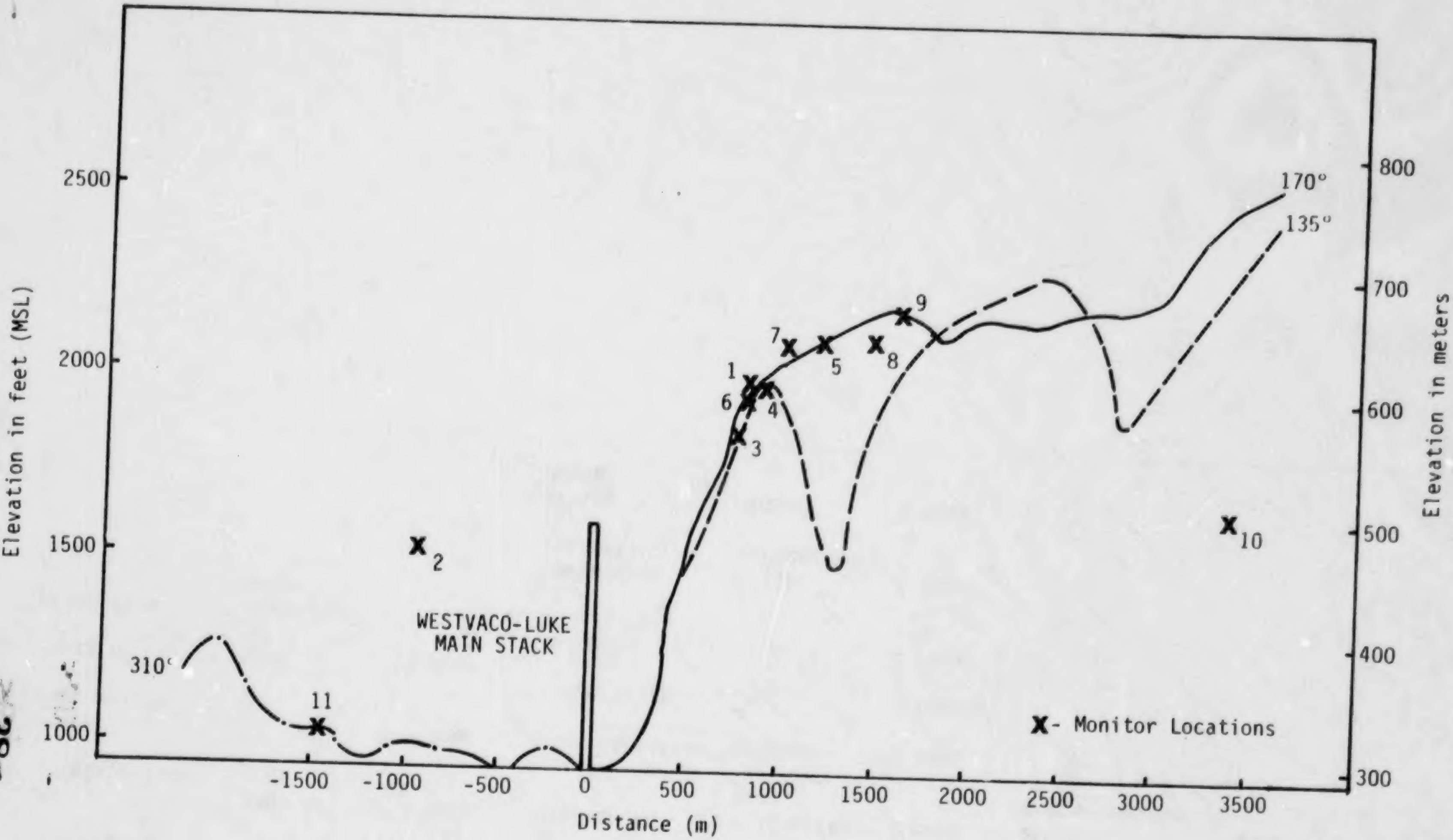


Figure 3-5. Westvaco vertical cross sections for radials of 135°, 170° and 310°. The Westvaco stack height along with monitor heights and distance are superimposed.

TABLE 3-5

UNITS AND AVERAGING TIMES CORRESPONDING TO MEASURED VARIABLES
REPORTED IN THE WESTVACO DATA BASE

Source			Meteorological			Ambient Air Quality		
Parameter	Units	Averaging Time	Parameter	Units	Averaging Time	Parameter	Units	Averaging Time
SO_2 emission rate	tons hr^{-1}	1 hour	wind speed	x 10 miles hour^{-1}	1 hour	SO_2 concentration	ppm	1 hour
stack temperature	°F	1 hour	wind direction	degrees	1 hour			
stack SO_2	ppm	1 hour	temperature	°F	1 hour			
steam flow	1000 lbs hour^{-1}		delta temperature	x 10 °F	1 hour			
			turbulence intensity	x 10^3 radians	1 hour			
			mixing depth	meters	1 hour			

TABLE 3-6

INSTRUMENTATION AND PARAMETERS MEASURED ON THE WESTVACO METEOROLOGICAL TOWERS

Site	Instruments*	Parameters
Beryl Tower		
Level 0 (10 m)	Cup and vane	SP, DR, IX, IY,
	Propeller anemometer	W, IZ
	Temperature probe	T
Level 1 (100 m)	Cup and vane	SP, DR, IX, IY,
	Propeller anemometer	W, IZ
	Delta temperature sensor	ΔT(100 m - 10 m)
Luke Hill Tower		
Level 0 (10 m)	Cup and vane	SP, DR, IX, IY,
	Propeller anemometer	W, IZ
	Delta temperature sensor	ΔT (10 m - 2 m)
Level 1 (30 m)	Cup and vane	SP, DR, IX, IY,
	Propeller anemometer	W, IZ
	Delta temperature sensor	ΔT (30 m - 10 m)
Met Tower		
Level 0 (10 m)	Cup and vane	SP, DR, IX, IY,
	Propeller anemometer	W, IZ
	Temperature probe	T
	Delta temperature sensor	ΔT (10 m - 2 m)

---

* All temperature sensors were mounted in aspirated radiation shields.

(continued on next page)

TABLE 3-6 (Continued)

Level 1 (50 m)	Cup and vane Propeller	SP, DR, IX, IY W, IZ
Level 2 (100 m)	Cup and vane Propeller Delta temperature sensor	SP, DR, IX, IY W, IZ ΔT (100 m - 10 m)

Key

W: vertical wind speed
SP: horizontal wind speed
DR: horizontal wind direction
IX: downwind intensity of turbulence
IY: crosswind intensity of turbulence
IZ: vertical intensity of turbulence
T: temperature
ΔT: temperature difference

The meteorological data base contains sequential hourly-averaged values of the parameters mentioned above. Table 3-5 indicates the units that meteorological data have been reported in.

Ambient Air Quality Data

Monitors for measuring ambient SO_2 concentrations were established at 11 sites (see Figure 3-3). Eight of these sites were located within plant property boundaries (from 800 to 1,500 m from the stack) on the high terrain east and south of the mill. Ground-level elevations at these monitors exceed the physical stack height. Two additional monitors, Luke Hill and Stony Run, were located 900 m north-northwest and 3,300 m northeast of the stack, respectively. Terrain elevations for these two monitors are nearly level with stack top. The remaining monitor, Bloomington, located 1,500 m northwest of the stack, is in a valley where the elevation is comparable to stack base elevation.

The air quality data base reports the sequential hourly-average values of the SO_2 concentrations measured at each of the 11 sites. Units ascribed to each of the variables are given in Table 3-5.

Data Selected for Model Input

The hourly averaged measurements obtained during the Westvaco-Luke field program were first reduced by ERT and then compiled by H.E. Cramer Company into a modelers' data base (MDB) for input to the SHORTZ and LUMM* models.[23] Most of the model inputs were obtained from this MDB, however, some additional data were compiled by TRC in order to meet all technical requirements of the complex terrain models. The data inputs were restricted to the second full year of measurements, December 1980 through November 1981.

Source Information

The source parameters, stack location (x, y, z), stack height and stack diameter, were input as constant values to each of the models. The following source parameters were input to the models on an hourly basis:

Q	Hourly SO_2 emission rate
T	Hourly stack gas exit temperature
VF	Hourly stack gas volume flow rate, or
V_s	Hourly stack gas exit velocity

In preparing the MDB, any missing values of Q, T, VF, or V_s were substituted with the last reported value.

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*The Luke Mill Model (LUMM) was developed specifically for the Westvaco-Luke Mill site.

Air Quality Data

Hourly SO_2 concentrations at each of the eleven monitors were recorded in units of parts per trillion. Prior to the evaluation these concentrations were converted to ug/m^3 through the use of hourly on-site temperatures and an average atmospheric pressure (from the U.S. Standard Atmosphere) of 0.96 atmosphere. Receptor locations and elevations were directly input to each of the models, although the horizontal coordinates first had to be converted to source-oriented distance and direction for input to RTDM and COMPLEX/PFM.

Model predictions for the Stony Run monitor (labeled receptor No. 10) could not be made with the IMPACT model due to grid size constraints and computer limitations. The other IMPACT receptors were located in the center of the nearest grid cell.

Meteorology

The Westvaco MDB of meteorological data was developed by H.E. Cramer Company[23] to meet the input needs of the SHORTZ and LUMM models. The specific parameters and their corresponding primary data sources are listed in Table 3-7. In preparing the MDB, alternate sources of meteorological data were preferentially ranked for use when data from the primary source were unavailable or unreliable for certain time periods. These data substitutions are shown in Table 3-8.

The meteorological data provided in the MDB was supplemented with other on-site tower data as well as some off-site data needed as input to the models. Table 3-9 summarizes all of the Westvaco meteorological inputs to the complex terrain models.

Data from off-site locations were used to characterize stability category for four of the models (COMPLEX I, COMPLEX II, COMPLEX/PFM, and 4141), mixing height for most of the models (except IMPACT) and, for COMPLEX/PFM, profiles of wind speed and temperature. The CRSTER preprocessor program was utilized with cloud cover data from the nearest National Weather Service station (Morgantown, WV) in conjunction with Westvaco 10 m wind speeds (averaged from the three towers) to categorize stability. Mixing heights were developed from twice daily Pittsburgh mixing heights as obtained from the National Climatic Center, and interpolated to hourly values using the various model preprocessor programs. (The interpolation scheme used to generate hourly mixing heights for COMPLEX/PFM has been changed since the model was submitted for this study.) The Pittsburgh twice per day radiosonde data (TDF5600 tape) were employed along with Westvaco tower data in the PROFILE program to generate hourly vertical profiles of wind speed and temperature. These profile data are used by COMPLEX/PFM to calculate Froude number and critical streamline height.

TABLE 3-7

PRIMARY HOURLY METEOROLOGICAL INPUTS INCLUDED IN THE WESTVACO MODELERS' DATA BASE AS COMPILED BY H.E. CRAMER ASSOCIATES[23]

Input Parameter	Primary Source
Transport Wind Direction	100 m level of Tower 1
Reference Level Wind Speed	30 m level of Tower 2
Wind Profile Exponents	Based on speed difference between upper levels of Tower 1 and 2
Vertical Potential Temperature Gradient	Based on temperature difference between the 10 m level of Tower 2 and 100 m level of Tower 1
Ambient Air Temperature	10 m level of Tower 2
Lateral and Vertical Turbulent Intensities	30 m level of Tower 2
Mixing Depths	A constant value of 1000 m
Stability Class[1]	From vertical turbulent intensity, 10 m level of Tower 2
Vertical Wind Direction Shear[2]	Direction difference between upper levels of Tower 1 and 2

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[1] Using the stability classification scheme suggested by EPA for a surface roughness length of 15 centimeters: A < 0.2094 (stability class/turbulent intensity in rad); B from 0.1746 to 0.2094; C from 0.1362 to 0.1745; D from 0.0874 to 0.1361; E from 0.0419 to 0.0873; and F < 0.0419.

[2] Needed only for the modified version of SHORTZ submitted for evaluation.

TABLE 3-8

DATA SUBSTITUTIONS USED BY H.E. CRAMER ASSOCIATES IN DEVELOPING WESTVACO HOURLY METEOROLOGICAL INPUTS[23]

Input Parameter	Rank of Parameter Source	Parameter Source
Transport Wind Direction[1]	1	100 m Level of Tower No. 1
	2	50 m Level of Tower No. 1
	3	10 m Level of Tower No. 1
	4	30 m Level of Tower No. 2
	5	10 m Level of Tower No. 2
Reference Level Wind Speed[2]	1	30 m Level of Tower No. 2
	2	10 m Level of Tower No. 1
	3	50 m Level of Tower No. 1
	4	100 m Level of Tower No. 1
	5	10 m Level of Tower No. 2
Vertical Wind-Direction Shear[3]	1	Direction difference between 100 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	2	Direction difference between 50 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	3	Direction difference between 10 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	4	Direction difference between 100 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	5	Direction difference between 50 m Level of Tower No. 1 and 10 m Level of Tower No. 2

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TABLE 3-8 (continued)

DATA SUBSTITUTIONS USED BY H.E. CRAMER ASSOCIATES
IN DEVELOPING WESTVACO HOURLY METEOROLOGICAL INPUTS[23]

Input Parameter	Rank of Parameter Source	Parameter Source
	6	Direction difference between 10 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	7	Direction difference between 100 m and 10 m levels of Tower No. 1
	8	Direction difference between 50 m and 10 m levels of Tower No. 2
Wind-Profile Exponent[4]	1	Based on speed difference between 100 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	2	Based on speed difference between 50 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	3	Based on speed difference between 10 m Level of Tower No. 1 and 30 m Level of Tower No. 2
	4	Based on speed difference between 100 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	5	Based on speed difference between 50 m Level of Tower No. 1 and 10 m Level of Tower No. 2

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TABLE 3-8 (continued)

DATA SUBSTITUTIONS USED BY H.E. CRAMER ASSOCIATES IN DEVELOPING WESTVACO HOURLY METEOROLOGICAL INPUTS[23]

Input Parameter	Rank of Parameter Source	Parameter Source
	6	Based on speed difference between 10 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	7	Based on speed difference between 100 m Level of Tower No. 1 and 10 m Level of Tower No. 1
	8	Based on speed difference between 50 m Level of Tower No. 1 and 10 m Level of Tower No. 1
Vertical Potential Temperature Gradient[5]	1	Based on temperature difference between 100 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	2	Based on temperature difference between 10 m Level of Tower No. 1 and 10 m Level of Tower No. 2
	3	Based on temperature difference between 100 m Level of Tower No. 1 and 10 m Level of Tower No. 1
	4	Based on temperature difference between 30 m Level of Tower No. 2 and 10 m Level of Tower No. 2
Ambient Air Temperature	1	10 m Level of Tower No. 2
	2	10 m Level of Tower No. 1
	3	10 m Level of Beryl Tower

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TABLE 3-8 (continued)

DATA SUBSTITUTIONS USED BY H.E. CRAMER ASSOCIATES
IN DEVELOPING WESTVACO HOURLY METEOROLOGICAL INPUTS[23]

Input Parameter	Rank of Parameter Source	Parameter Source
Lateral and Vertical Turbulent Intensities	1	30 m Level of Tower No. 2
	2	10 m Level of Tower No. 1
	3	50 m Level of Tower No. 1
	4	100 m Level of Tower No. 1
	5	10 m Level of Tower No. 2
Stability Class	1	10 m Level of Tower No. 2
	2	10 m Level of Tower No. 1
	3	30 m Level of Tower No. 2
	4	50 m Level of Tower No. 1
	5	100 m Level of Tower No. 1

[1] When no non-variable wind direction was found, the hour was flagged by setting the wind direction equal to 090 degrees and the mixing depth equal to 1 meter.

[2] Wind speeds above 0, but less than 1 meter per second, were set equal to 1 meter per second. When all of the wind speeds were calm, the hour was flagged by setting the wind direction equal to 090 degrees and the mixing depth equal to 1 meter.

[3] When none of the data substitutions were possible, the wind-direction shear was set equal to zero.

[4] The wind-profile exponent was set equal to zero when the calculated exponent was negative or if none of the data substitutions were possible. The wind profile exponent was not allowed to exceed unity.

[5] When none of the data substitutions were possible, the vertical potential temperature gradient was set equal to the moist adiabatic value of 0.003 degrees Kelvin per meter.

[6] When no turbulence measurements were available, the lateral and/or vertical turbulent intensities substituted were climatological values for the combination of season, wind speed and time-of-day categories.

TABLE 3-9

SUMMARY OF WESTVACO METEOROLOGICAL INPUTS TO THE COMPLEX TERRAIN MODELS

Model Function	Input Parameter	Model CX1	 CX2	 PFM	 M41	 IMP	 PL5	 RTD	 SHZ
Transport	Wind Speed	U-1	U-1	U-1	U-1	U-2	U-1	U-3	U-4
	Wind Direction	Θ-1	Θ-1	Θ-1	Θ-1	Θ-2	Θ-1	Θ-1	Θ-1
	Wind Dir. Shear	NR	NR	NR	NR	NR	NR	NR	NR
	Anemometer Ht.	Z-1	Z-1	Z-1	Z-1	Z-1	Z-1	Z-2	Z-1
	Power Law Exponents	NR	NR	NR	NR	NR	NR	P-2	P-1
Dispersion	Stability	S-1	S-1	S-1	S-1	S-4	S-2	S-3	NR
	Horiz. Turb.	NR	NR	NR	NR	NR	NR	I_y2	I_y1
	Vert. Turb.	NR	NR	NR	NR	NR	NR	I_z2	I_z1
Plume Rise	Temperature	T-1	T-1	T-2	T-1	T-1	T-1	T-1	T-1
	Wind Speed	U-1	U-1	U-6	U-1	U-2	U-1	U-5	U-1
	dT/dZ	NR	NR	NR	NR	NR	NR	DT1	DT1
	Stability	S-1	S-1	S-1	S-1	S-4	S-2	S-3	NR
Limited Mixing	Mixing Height	L-1	L-1	L-4	L-1	NR	L-2	L-1	L-3
Critical Height	Temperature	NR	NR	U-6	NR	NR	NR	DT1	NR
	Wind Speed	NR	NR	T-2	NR	NR	NR	U-1	NR

Legend		Description
Model	CX1	COMPLEX I
	CX2	COMPLEX II
	PFM	COMPLEX/PFM
	M41	4141
	IMP	IMPACT
	PL5	PLUME5
	RTD	RTDM
	SHZ	SHORTZ

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TABLE 3-9 (Continued)

Legend		Description
Wind Speed	U-1	"Stack height" wind speed from Westvaco modelers'data base (MDB)
	U-2	Wind speed from 3 towers, all levels; interpolated to mid-grid cell
	U-3	U-1 extrapolated to plume height from Z-2 using P-2
	U-4	U-1 extrapolated to plume height from Z-2 using P-1
	U-5	U-1 extrapolated to stack height from Z-2 using P-2
	U-6	Profile of speeds from all tower levels merged with Pittsburgh radiosonde data through PROFILE (COMPLEX/PFM preprocessor)
Wind Direction	Θ-1	"Transport height" wind direction from MDB
	Θ-2	Wind direction from 3 towers, all levels; interpolated to mid-grid cell
Wind Direction Shear	ΔΘ1	From MDB
	ΔΘ2	$d\Theta/dz = \Delta\Theta 1/70$ m
Anemometer Height	Z-1	Set to stack top (189.7 m) since U-1 represents stack top wind
	Z-2	Z = 30 m (Tower 2 height), ZA = 179.6 m (Tower 2 base relative to stack base)
Power Law Exponents	P-1	Hourly from MDB
	P-2	As for P-1 but with observed negative values (from ERT)
Stability	S-1	P-G category from Turner method (CRSTER preprocessor) using Morgantown, WV cloud data and Westvaco 10 m wind speed (Avg. of 3 towers)
	S-2	P-G category from CONVRT (PLUME5 preprocessor) using σ_θ (I_y from MDB)
	S-3	P-G category using σ_ϕ (I_z on 50 m level of Tower 2, from ERT)
	S-4	Vertical profile of P-G category based on $d\Theta/dz$ from temperatures on 3 towers

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TABLE 3-9 (Continued)

Key		Description
Turbulence - Y	I_y1	Horizontal turbulence from MDB
	I_y2	Horizontal turbulence measured at 50 m on Tower 1 (from ERT)
Turbulence - Z	I_z1	Vertical turbulence from MDB
	I_z2	Vertical turbulence measured at 50 m on Tower 1 (from ERT)
Temperature	T-1	From MDB
	T-2	Profile of temperatures from all tower levels merged with Pittsburgh radiosonde data through PROFILE (COMPLEX/PFM preprocessor)
dT/dZ	DT1	Vertical potential temperature gradient from MDB
Mixing Height	L-1	From CRSTER preprocessor with Pittsburgh (Upper) and S-1
	L-2	From CONVRT (PLUME5 preprocessor) with Pittsburgh (Upper) and S-2
	L-3	From METZ (SHORTZ preprocessor) with Pittsburgh (Upper) and Westvaco 10 m wind speed
	L-4	From PROFILE (COMPLEX/PFM preprocessor) with Pittsburgh (Upper)
	NR	Not required

SECTION 4

STATISTICS APPROACH

The 1980 AMS Woods Hole workshop on model performance evaluation recommended a comprehensive list of performance measures and statistics for evaluating air quality models. The workshop recommended that performance evaluations be based on comparisons of the full set of observed-predicted data pairs, of the highest observed and predicted concentration per event (e.g., 1, 3 or 24 hour time period) and of the highest N values (unpaired in time or space). In addition, comparisons of observed and predicted concentrations are to be carried out on data subsets representing individual monitoring stations or selected meteorological conditions.

TRC and EPA reviewed the workshop report and formulated a statistical approach for the rural model evaluations[3] based on workshop recommendations. The approach was modified for the urban model evaluations[5], primarily to reduce the volume of information by eliminating redundant performance measures and statistics. Additional revisions as appropriate to the complex terrain models were also made, and the statistical approach followed for this evaluation is described below.

DATA SETS FOR COMPARISON OF OBSERVED AND PREDICTED CONCENTRATIONS

The data sets listed in Table 4-1 represent the different types of comparisons recommended by the AMS workshop. In each instance, comparisons were recommended for the basic 1-hour unit for model predictions and also for 3-hour and 24-hour averaging times. The numbering scheme in the table is derived from a summary prepared by William Cox of EPA of the data sets and statistics recommended by the AMS workshop.

To compare observed and predicted air quality values on a common basis, it is necessary to account for background concentration, i.e., contributions to measured air quality from sources whose impact is not modeled. This concern does not arise for the Cinder Cone Butte tracer study, since other sources of SF_6 are non-existent. The effects of background in the Westvaco monitored data were removed from measured SO_2 concentrations before statistical comparisons were made between observed and predicted concentrations. The uncertainty of plume transport in complex terrain poses an uncertainty in attempting to define a method for the determination of background concentrations. High observed concentrations in the Westvaco network tended to occur with light and variable winds which can result in

TABLE 4-1. SUMMARY OF DATA SETS FOR MODEL EVALUATION

Peak Concentration Comparisons	(A-1)	Compare highest observed value for each event with highest prediction for same event (paired in time, not location)
	(A-2)	Compare highest observed values for the year at each monitoring station with the highest prediction for the year at the same station (paired in location, not time)
	(A-3a)	Compare maximum observed value for the year with highest predicted values representing different time or space pairing (fully unpaired, paired in location; paired in time; paired in space and time)
	(A-3b)	Compare maximum predicted value for the year with highest observed values for various pairings, as in (A-3a)
	(A-4a)	Compare highest N (=25) observed and highest N predicted values, regardless of time or location
	(A-4b)	Compare highest N(=25) observed and highest N predicted values, regardless of time, for a given monitoring location. (A total of 11 data sets.)
	(A-5)	Same as (A-4a), but for subsets of events by meteorological conditions (stability and wind speed) and by time of day.
B. All-Concentrations Comparisons	(B-1)	Compare observed and predicted values at a given station, paired in time (a total of 11 data sets).
	(B-2)	Compare observed and predicted values for a given time period, paired in space (not appropriate for data sets with few monitoring sites).
	(B-3)	Compare observed and predicted values at all stations, paired in time and location (one data set) and by time of day.
	(B-4)	Same as (B-3), but for subsets of events by meteorological conditions (stability and wind speed) and by time of day.

high measured concentrations at monitors located 180° upwind from the stack, using the measured wind direction. It was assumed that the background contribution is evenly distributed over the study area, and can be represented by the lowest measured concentration in the network each hour. Since observed concentrations of less than .005 parts per million (ppm) were set to the minimum instrument detection level of .005 ppm, background concentrations for these hours were set to .0025 ppm. The Luke Mill of Westvaco is relatively isolated from other point sources of SO_2, so this background method should be effective. In Table 4-1, and in the discussions that follow, "observed value" denotes a measured concentration minus background.

For many hours during the year at Westvaco, none of the monitoring stations experienced significant observed or predicted SO_2 impact. These hours of effectively zero observed and zero predicted impact are relatively uninteresting for the evaluation of air quality models for regulatory purposes. Including those hours in statistical analyses adds to the computational burden and tends to dilute the model performance results from hours with significant impact. Consequently, threshold values were imposed to screen the data base for statistical analyses. If, for a given time period, both the observed concentration and the predicted concentration at a station were below the threshold, that data pair was excluded from further analysis. A threshold value of 25 µg/m^3 was used for 1-hour and 3-hour averages, and a value of 5 µg/m^3 was used for 24-hour averages. Threshold checks were not imposed on the Cinder Cone Butte data.

Peak Concentrations

For peak concentrations, comparisons are made to determine model performance both on an unpaired basis and for various pairings in time and space. The first two items in Table 4-1 represent a comparison of the highest observed and highest predicted concentrations, paired in time (A-1) and paired in location (A-2). For the Westvaco data set, these two comparisons provide quite different measures of performance since the number of events is large (1 year represents 365 days or 8,760 hours) while there are only 11 stations. Meanwhile for the Cinder Cone Butte data set, the number of events is relatively small (104 hours) while the number of stations (94) is relatively large. An additional (A-2) data set was added for the complex terrain evaluation, representing the second-highest values observed and predicted at each station.

Item A-3a represents a comparison of the highest observed concentration values, regardless of time or space, and predicted values representing different time and space pairing. Item A-3b is directly analogous to A-3a, but starts from the highest predicted value. Results for data sets (A-3a) and (A-3b) were relatively uninformative for the rural evaluation. These sets were therefore dropped from subsequent evaluations.

Items A-4 and A-5 involve comparisons of the "N" highest observed and predicted values, unpaired in time or space. The AMS workshop recommended that such comparisons be based on the upper 2 to 5 percent of concentrations, rather than on one or two extreme values. As an alternative to the percentile approach, TRC recommended using a small number (N=25) which would more appropriately represent the set of highest observed and predicted values, while still providing a statistical basis for establishing confidence limits. On a percentage basis, 25 values represent roughly 7 percent of the 365 24-hour values in a year, about 1 percent of the 3-hour values, and about 0.3 percent of the 1-hour values.

Air quality data often exhibit spatial and temporal correlation, particularly over time periods of a few hours. For 1-hour and 3-hour periods, the highest 25 values were screened to eliminate cases with two or more high values from the same period, or with two consecutive high values (Westvaco only) at the same location. This screening is intended to reduce the effects of auto-correlation and to avoid double-counting a single event. For 24-hour averaging periods, less correlation is expected, and this screening was not included.

Comparisons of the highest 25 observed and predicted values were performed for all stations combined (A-4a), for each station individually (A-4b) and for subsets of events corresponding to selected source-receptor geometry and to selected meteorological conditions (A-5). The subsets selected for the evaluation of each data base are described in more detail later in this section.

Comparisons of All Concentrations

In addition to peak concentration analyses, the AMS workshop recommended that comparisons be made based upon all observed and predicted concentration values. Table 4-1 lists three items of this type. Item B-1 is the comparison of observed and predicted values at a given monitoring station (for all data pairs above the threshold values). Item B-3 represents comparisons based on the set of values from all 11 stations combined. Item B-4 represents subsets of B-3. The same criteria described for item A-5 above (for defining subsets of source-receptor geometry and meteorology) were used to define subsets for comparisons of all concentrations.

STATISTICAL ANALYSIS OF MODEL PERFORMANCE

The AMS workshop report recommended two somewhat different lists of performance measures for comparing model predictions with observed air quality, one appropriate for data sets representing pairs of observed and predicted values, the other appropriate for unpaired data sets. Paired data sets provide a means for assessing how well a model predicts on an event-by-event basis, while unpaired sets do not. Table 4-2 summarizes the basic list of performance measures, and the statistical methods recommended for establishing confidence limits on each measure. At the head of each column (Paired and Unpaired) are listed the data sets from Table 4-1 to which each list of measures and statistical methods has been applied.

TABLE 4-2. STATISTICAL ESTIMATORS AND BASIS FOR CONFIDENCE LIMITS ON PERFORMANCE MEASURES

Performance Measure	Estimator	Basis for Confidence Interval	
		Paired Comparison (Sets A-1, A-2, B-1, B-3, B-4)*	Unpaired Comparison (Sets A-1, A-4, A-5, B-1, B-3, B-4)
Bias	Average	One sample "t," with adjustment for serial correlation	Two sample "t"
	Median	Wilcoxon match pair	Mann-Whitney
Noise/Scatter	Variance	Chi-squared test on variance of residuals	F test on variance ratio
	Gross variability	None	Not applicable
	Average absolute residual	None	Not applicable
Correlation	Pearson correlation coefficient	Fisher "z"	Not applicable
Frequency distribution comparison	Maximum difference between two cumulative distribution functions	Not Applicable	Kolmogorov-Smirnov (K-S) test on f (obs.) vs. f (pred.)

* These sets refer to Table 4-1.

The data sets from item A-1 (highest observed and predicted values for each event) and from items B-1, B-3, and B-4 all represent observed and predicted values paired in time. For these sets, statistical analyses based on the residual (i.e., the differences between each pair of observed and predicted values) are appropriate for measuring model performance. If the time pairing for these data sets is ignored, however, it is also possible to assess model performance (in aggregate) by comparing the features of the composite set of all observed values to those of the predicted values. Consequently, both paired and unpaired comparisons were recommended by the AMS workshop for these data sets. Data sets representing comparisons of the highest 25 values, regardless of time or space, provide no basis for paired analysis. For these sets (A-4, A-5), only unpaired comparisons were performed. Item A-2 represents comparison of the single highest observed and predicted values from each of the N stations. Only the paired comparison performance measures were computed for this case. No statistics were computed for the single-value comparisons in item A-3.

For paired comparisons, as noted above, the performance measures are based on an analysis of residuals. Model bias is indicated by the average and/or the median residual, with a value of zero representing no bias. The characteristic magnitude of the residuals is an indicator of the scatter between observed and predicted values on an event-by-event basis. Three measures of noise or scatter were computed:

- Variance $\frac{1}{N-1} \sum_{i} (d_i - \bar{d})^2$

- Gross variability $\frac{1}{N} \sum_{i} d_i^2$

- Average absolute residual $\frac{1}{N} \sum_{i} |d_i|$

where d_i is the residual (observed minus predicted) for data pair i, d is the average residual, and N is the number of data pairs. The correlation of paired observed and predicted values is measured by the Pearson correlation coefficient.

For unpaired comparisons, the list of performance measures is somewhat shorter. Model bias is indicated by the difference between the average (or median) observed value and the average (median) predicted value. A ratio of the variances of the observed and predicted values is provided to indicate whether the distribution of values in the two data sets is comparable. Similarly, the frequency distribution of observed values is compared with that for predicted values.

Standard statistical methods have been used to estimate confidence limits for each of the performance measures. Discussion of the statistical procedures may be found in most statistics textbooks. For parametric procedures, the reader is referred to Snedecor and Cochran (1967),[24] while for nonparametric procedures Hollander and Wolfe (1973)[25] provide an appropriate description.

For paired comparisons, the confidence interval on the average residual can be estimated using the one-sample t test. This parametric test incorporates the assumption that the residuals follow a normal distribution, but for large N departures from normality are not critical. Serial correlation can affect results significantly, however, since the number of "independent events" will be overestimated and the calculated variance may understate the magnitude of the actual random error component. The AMS workshop recommended the adjustment of confidence limits for serial correlation. A method described by Hirtzel and Quon (1981)[26] has been used to adjust the confidence interval from the one-sample t test. The interval given by the standard one-sample t test is multiplied by the factor $[(1+r)/(1-r)]^{1/2}$, where r is the lag-one autocorrelation coefficient of the residuals.

An analogous nonparametric indicator of model bias is the median residual. The statistical method for estimating a confidence interval on the median residual is provided by the Wilcoxon matched-pairs test. No straightforward method of adjusting the confidence intervals from the Wilcoxon test for serial correlation has been identified.

A confidence interval for the variance of the residuals is calculated using a chi-squared test. No adjustment was made for serial correlation. No standard method is available for estimating confidence intervals for the gross variability or average absolute deviation measures. For the Pearson correlation coefficient, the Fisher z test provides a method of estimating the confidence interval.

Comparison of two cumulative distribution functions is accomplished using the Kolmogorov-Smirnov (K-S) test. For this test, the two distribution functions are compared across the full range of concentration (or residual) values, and the maximum frequency difference between the two functions is identified.

For unpaired comparisons, two bias measures are computed. The average of the observed values is compared with the average of the predicted values. The confidence interval on the difference of the averages is estimated with a two-sample t test. The median difference is also computed, and the confidence interval is estimated using the Mann-Whitney nonparametric test.

The variance of observed values is compared with the variance of predicted values for unpaired data sets. The performance measure is the ratio of the variances; the F test provides confidence limits on the ratio.

The frequency distribution comparison for unpaired data sets provides a measure of the difference between the observed and predicted distribution functions. The K-S test is again used to assess the statistical significance of the maximum frequency difference.

Statistical Measures for the Full Westvaco Data Set

For Westvaco, the full data set represents hourly observed and predicted concentrations at each receptor and hourly associated variables (for subset analysis) for a one-year period of record. The specific performance measures and statistics calculated for each of the unpaired and paired data sets are summarized in Table 4-3 and 4-4. The notation for identifying data sets corresponds to that employed in Table 4-1.

The routine monitoring network at Westvaco, with relatively few stations and a very large number of events lends itself to an evaluation approach focussed on peak values (unpaired in time or location), analysis by station, and analysis for meteorological subsets (by stability and wind speed). The added factor of terrain elevation is reflected in station-by-station results. The performance evaluation considers 1-hour, 3-hour, and 24-hour averaging times. In complex terrain, peak impacts are commonly thought to be associated with stable conditions. Four stability categories, therefore, have been selected: unstable (Class A, B, and C); neutral (Class D); slightly stable (Class E); and stable (Class F).

Table 4-3 indicates that the full set of estimators and confidence interval calculations will be provided for the 25 highest values over all stations and events (A-4a), but only a partial set of measures is provided by station (A-4b) or for subsets by meteorology (A-5).

For the paired data sets (Table 4-4), the highest priority is placed on comparisons of the highest value per station (A-2) and all events paired in time and location (B-3). The remaining data sets received a more limited analysis.

IMPACT Model: Analysis of Select Hours for Westvaco

The IMPACT model runs with Westvaco data were limited to selected periods in order to maintain reasonable computer costs. As previously discussed, the primary basis for evaluating the models (except IMPACT) with the Westvaco data is the set of performance statistics based on the full year of Westvaco data. In order to provide some basis for comparing the performance of the IMPACT model and the other complex terrain models, performance statistics have been prepared for the other models based on the same subset of hours selected for evaluation of the IMPACT model.

Based on benchmark computer costs, it was estimated that approximately 500 hours could be simulated with the IMPACT model. Selection of this many hours allowed the consideration of 24-hour as well as 3-hour and 1-hour averaging periods. However, the number of 24-hour periods, restricted to about twenty is marginal from a statistical standpoint. The selection of twenty 24-hour periods did ensure that a large number of 1-hour and 3-hour

TABLE 4-3. PERFORMANCE MEASURES AND STATISTICS CALCULATED FOR THE WESTVACO UNPAIRED (25 HIGHEST) DATA SETS

	Average Observed	Average Predicted	Difference of Averages	Median Difference	Variance Ratio
All stations/ all events (A-4a)	✓	✓	✓(C.I.)*	✓(C.I.)	✓(C.I.)
By station/ all events (A-4b)	✓	✓	✓	X	✓
Subsets by met. conditions (A-5)	✓	✓	✓	X	✓

* C.I. = confidence interval

Subsets include: Stability Class (4 groups): Class A, B, C
Class D
Class E
Class F

Wind Speed (3 groups)

Averaging times: 1, 3, 24 hours

TABLE 4-4. PERFORMANCE MEASURES AND STATISTICS CALCULATED FOR WESTVACO DATA SETS PAIRED IN TIME OR LOCATION

	Highest per event paired in time (A-1)	Highest per station paired by location (A-2)	All data paired in time and location (B-3)	All events at each station paired in time (B-1)	Subsets of events paired in time and location (B-4)
Number of events	✓	✓	✓	✓	✓
Average observed	✓	✓	✓	✓	✓
Average difference	✓(C.I.)*	✓(C.I.)	✓(C.I.)	✓	✓
Fraction Co > Cp	x	✓	✓	x	x
Characteristic Discrepancies					
σ_d	✓(C.I.)	✓(C.I.)	✓(C.I.)	✓	✓
RMSE	x	✓	✓	x	x
AAR	x	✓	✓	x	x
Correlation Coefficients					
Pearson R	x	✓	✓	x	
Spearman ρ	x	✓	✓	x	x
Variance comparison	x	✓(C.I.)	✓(C.I.)	x	x
Maximum frequency difference	✓(C.I.)	x	✓(C.I.)	x	x

* C.I. = confidence interval

periods were modeled. Not all these periods, however, involve significant observed and predicted impact at monitor locations. The following selection criteria were followed:

1. The days with the six highest observed concentrations at each of the 10 monitors to be modeled with the IMPACT model were identified.
2. 20 days (480 hours) were randomly selected from (1).
3. The 3-hour periods with the six highest observed concentrations at each of the 10 monitors were identified as in (1).
4. 20 3-hour periods were randomly selected from (3).

Model results for the hours selected in (2) and (4) above were then analyzed. Implementation of the above criteria resulted in a data set containing 480 hours. Performance statistics for this limited data set include only a portion of the measures listed in Tables 4-3 and 4-4. For unpaired (25 highest) analysis, the all stations/all events case was examined for the 1-hour averaging period. For data sets paired in time or location (Table 4-4), statistics for A-1, A-2, B-1, and B-3 were generated for the 1-hour average, but subsets of events (B-4) were not considered.

Statistical Measures for the Cinder Cone Butte Data Set

The tracer experiments at Cinder Cone Butte represent a different type of data set for evaluating model performance. The number of concentration measurements per hour is much greater, and the number of events much fewer, than those from a long-term, continuous monitoring program. The greater spatial density of measurements make comparisons between observed and predicted values event-by-event (paired in time) more informative for a tracer data set. Analyses for individual hours and/or individual tests are also feasible. By contrast, the number of monitors and the use of movable arrays make it difficult to perform station-by-station analyses.

The evaluation for Cinder Cone Butte shifts the emphasis toward event-by-event analysis. The Cinder Cone Butte data sets representing the 25 highest observed and predicted values (unpaired) received similar treatment to that for Westvaco, as indicated by Table 4-5. No analysis by station has been attempted. Subset analysis included station groups defined by receptor terrain elevation (relative to release height). Receptors were grouped into four categories: below release height; at release height (within 10 meters); between 10 and 30 meters above release height; and more than 30 meters above release height.

The paired data sets analysis for Cinder Cone Butte, summarized in Table 4-6, does not include any analyses by station. The highest-by-event data set (A-1) has been analyzed for the full set of paired performance measures, as was the "all pairs" (B-3) data set.

TABLE 4-5. PERFORMANCE MEASURES AND STATISTICS CALCULATED FOR THE CINDER CONE BUTTE UNPAIRED (25 HIGHEST) DATA SETS

	Average Observed	Average Predicted	Difference of Averages	Medians Difference	Variance Ratio
All stations/ all events (A-4A)	✓	✓	✓(C.I.)*	✓(C.I.)	✓(C.I.)
Subsets by receptor terrain elevation (A-5)	✓	✓	✓	x	✓

* C.I. = confidence interval

Averaging time: 1 hour only

TABLE 4-6. PERFORMANCE MEASURES AND STATISTICS CALCULATED FOR THE CINDER CONE BUTTE DATA SETS PAIRED IN TIME OR LOCATION

	Highest per event paired in time (A-1)	Highest per event paired in time-subsets (A-1a)	All data paired in time and location (B-3)	Subsets of events paired in time and location (B-4)
Number of events	✓	✓	✓	✓
Average observed	✓	✓	✓	✓
Average difference	✓(C.I.)*	✓	✓(C.I.)	✓
Fraction Co > Cp	✓	x	✓	x
Characteristic Discrepancies				
σd	✓(C.I.)	✓	✓(C.I.)	✓
RMSE	✓	x	✓	x
AAR	✓	x	✓	x
Correlation Coefficients				
Pearson R	✓	✓	✓	x
Spearman ρ	✓	x	✓	x
Variance comparison	✓(C.I.)	x	✓(C.I.)	x
Maximum frequency difference	✓(C.I.)	x	✓(C.I.)	x

* C.I. = confidence interval

Since the tracer releases for the Cinder Cone Butte experiments were generally shorter than three hours in duration (less than one hour in many instances), it was not feasible to evaluate model performance for averaging times as long as three hours. Analyses were limited to one-hour averaging periods.

For the Cinder Cone Butte data base, analysis of the unpaired 25 highest values for subsets of events was not attempted. Subset analysis was instead performed for the "highest-by-event" paired data set. The recommendation to replace "highest 25" subsets with "highest paired in time" subsets for Cinder Cone Butte reflects two considerations. First, the total number of events is small, and some subsets may contain fewer than 25 hours. Second, the sampler density provides relatively good estimates of peak values for all hours, and the experimental periods were generally selected to provide high impact at receptors.

Paired data subsets for Cinder Cone Butte (for 1-hour periods) were defined by stability group, wind speed, release hight and release distance. Stability group wind speed categories for Cinder Cone Butte are the same as those for Westvaco. Three release height categories (relative to the base elevation of 945 meters) were used: below 16 meters; between 16 and 26 meters; and above 26 meters. Two release distance categories were used: less than or greater than 900 meters from the release point to the top of the butte.

SECTION 5

MODEL PERFORMANCE RESULTS

Statistics comparing observed and predicted concentrations have been generated for each of the eight complex terrain models and two data bases. The results are presented by data set for the Westvaco full year model runs, Westvaco-IMPACT select hours, and Cinder Cone Butte tracer tests. Each data set is organized into four types of tables providing statistics for 25 highest values, highest concentrations by station (except for Cinder Cone Butte), highest concentrations by event and comparisons of all observed and predicted concentrations paired in space and time. Tables of statistical subsets by meteorology and source-receptor geometry are provided in Appendices B and C.

WESTVACO FULL YEAR RESULTS

The full year of Westvaco data was run for all of the models except IMPACT. Statistical measures were produced for three averaging times (1-hour, 3-hour, and 24 hours) for each of the seven complex terrain models.

Statistics for 25 Highest Values

Statistics for the set of 25 highest observed and 25 highest predicted 1-hour average SO_2 concentrations are presented for each model in Table 5-1. The first two columns of results are simply the average of the 25 highest observed values and the average of the 25 highest predicted values for each data set. The first performance measure, presented in column three is the difference between the two averages. A positive value implies model underprediction. In parentheses under the calculated differences are 95 percent confidence intervals, determined by using the two-sample Students' t test. These results show that all seven of the complex terrain models overpredicted the 25 highest values at the 95 percent confidence level. The largest overprediction, by a factor of 20, is by COMPLEX II, and the smallest overprediction, by a factor of 1.6, is by RTDM.

The second performance measure is the median difference (313th highest value) between all 625 possible pairings of the 25 highest observed and predicted concentrations. The 95 percent confidence interval is determined with the nonparametric Mann-Whitney test. Results for the median difference are very similar to those for the difference of averages.

TABLE 5-1

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	1969	18159	-16190 (-17143,-15243)	-15972 (-17144,-14542)	.017 (.008, .039)	1.00 (.383)
COMPLEXII	1969	39638	-35669 (-38555,-34782)	-35616 (-37307,-33968)	.004 (.002, .010)	1.00 (.383)
4141	1969	12205	-10236 (-11549, -8922)	-9556 (-11689, -8080)	.009 (.004, .020)	1.00 (.383)
RTDM	1969	3289	-1319 (-1652, -985)	-635 (-945, -282)	.151 (.067, .344)	.92 (.385)
PLUMES	1969	14525	-12556 (-13923,-11189)	-11472 (-12831,-10748)	.008 (.004, .019)	1.00 (.383)
COMPLEX/PFM	1969	15163	-13193 (-15397,-10989)	-11389 (-12329,-10520)	.003 (.001, .007)	1.00 (.383)
SHORTZ	1969	13563	-11594 (-13075,-10112)	-10153 (-11021, -9576)	.007 (.003, .015)	1.00 (.383)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

The third performance measure is the variance comparison. The variance of the 25 highest observed values was divided by the variance of the 25 highest predictions. The F test was used to calculate the 95 percent confidence levels for these comparisons. Results indicate that, for all of the models, the scatter of 25 highest model predicted concentrations is much larger than the scatter of 25 highest observations.

The last performance measure presented in Table 5-1 is the frequency distribution comparison. The cumulative distribution function f(C) represents the fraction of the data set (in this case, the fraction of 25 data points) with concentration values less than or equal to C. The value presented in this column is the largest absolute difference between the observed and predicted distribution functions (for the same concentration value) obtained when the two functions are compared for all concentration values. The value given in parentheses is the maximum difference which is significantly different from zero, at a 95 percent confidence level, as given by the Kolmogorov-Smirnov (K-S) test. This confidence interval is a function of the number of cases. The value is, therefore, the same (0.385) for all models, since the number of cases is always 25. The results for the comparison of maximum frequency differences (1.00 for six of the seven models) indicate there is no overlap between the distributions of 25 highest observations and 25 highest predictions.

Table 5-2 is presented to exemplify how comparisons of the 25 highest observations and 25 highest predictions selected by monitoring station and for various meteorological subsets reveal more detailed aspects of model performance. Results for the COMPLEX I model are depicted in Table 5-2, while results for all of the models are presented in Appendix B. Comparisons of median difference and frequency distributions have been eliminated from the subset tables since they don't provide a great deal of additional information.

While reviewing Table 5-2, the reader should notice from Figure 3-3 that the largest overpredictions by COMPLEX I occur at the close-in monitors (stations 1, 3, 4, and 6) on the ridge southwest of the stack; while underpredictions occur at the two monitors (stations 2 and 11) located northwest of the plant. Overpredictions of the highest 25 concentrations occur on average for all wind speed categories and for stable conditions. Neutral and unstable conditions, however, result in underpredictions of the highest 25 concentrations by COMPLEX I. The average of the 25 highest predictions for stability D is only 8 $\mu g/m^3$, while the observed average is 1517 $\mu g/m^3$, resulting in an extremely large variance ratio for this subset. For COMPLEX I (and some other models as well) this result is probably due to the half-height terrain treatment (lifting the plume over terrain) combined with small values of the vertical dispersion coefficients for stability D.

Comparisons of the highest 25 observed and predicted concentrations for data sets of 3-hour and 24-hour averaging periods are presented in Table 5-3 and 5-4. Subset tables for 3-hour and 24-hour averaging periods are

TABLE 5-2

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEX I
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	1969	18169	-16199 (-17149,-15249)	.017 (.008, .039)
STATION 1	1316	16574	-15257	.013
STATION 2	318	43	276	11.967
STATION 3	1113	12369	-11257	.264
STATION 4	1072	12089	-11015	.029
STATION 5	1374	8104	-6729	.176
STATION 6	1411	15372	-13960	.029
STATION 7	1347	8398	-7050	.024
STATION 8	1103	2354	-1250	.032
STATION 9	1183	4422	-3238	.056
STATION 10	339	428	-88	30.642
STATION 11	315	191	124	.754
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	1576	18169	-16592	.023
2.5 TO 5. M/S	1813	12828	-11013	.801
> 5. M/S	551	5664	-5111	.023
2. STABILITY GROUP				
CLASS A, B & C	1092	418	674	7.232
CLASS D	1517	8	1509	12133.506
CLASS E	1118	11859	-10741	.114
CLASS F	1667	18169	-16501	.027

TABLE 5-3

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	1127	12205	-11075 (-11845,-10311)	-10433 (-11000,-10157)	.026 (.011, .058)	1.00 (.385)
COMPLEXII	1127	20557	-19430 (-20871,-17988)	-17793 (-21880,-17031)	.007 (.003, .016)	1.00 (.385)
4141	1127	4769	-3642 (-4283, -3000)	-3552 (-4107, -2712)	.037 (.016, .084)	1.00 (.385)
RTDM	1127	1464	-337 (-545, -127)	-256 (-502, -135)	.473 (.209,1.075)	.52 (.385)
PLUME5	1127	7817	-6690 (-8051, -5329)	-5554 (-6958, -4625)	.008 (.004, .018)	1.00 (.385)
COMPLEX/PFM	1127	7728	-6601 (-7549, -5652)	-6053 (-6977, -5255)	.017 (.007, .038)	1.00 (.385)
SHORTZ	1127	5330	-5202 (-5780, -4624)	-5043 (-5370, -4323)	.046 (.020, .104)	1.00 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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TABLE 5-4

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	354	3238	-2883 (-3141, -2624)	-2728 (-2886, -2574)	.007 (.003, .017)	1.00 (.383)
COMPLEXII	354	4482	-4127 (-4657, -3597)	-3504 (-4221, -3306)	.002 (.001, .004)	1.00 (.383)
4141	354	855	-500 (-644, -357)	-382 (-443, -317)	.024 (.011, .055)	1.00 (.383)
RTDM	354	331	23 (-37, 83)	57 (32, 92)	.143 (.063, .324)	.55 (.395)
PLUMES	354	1712	-1357 (-2040, -674)	-730 (-892, -559)	.001 (.000, .002)	1.00 (.383)
COMPLEX/PFM	354	1584	-1229 (-1480, -978)	-1201 (-1393, -887)	.008 (.003, .019)	1.00 (.383)
SHORTZ	354	1388	-1033 (-1175, -891)	-944 (-1150, -824)	.025 (.011, .057)	1.00 (.383)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

presented in Appendix B. Results for 3-hour and 24-hour averages are similar to the results for the 1-hour averages. For 24-hour averages, RTDM predicted the average of the 25 highest values with no significant bias, at the 95 percent confidence interval.

Statistics for Highest Concentrations at Each Station

In Table 5-5 performance statistics are presented which compare the maximum concentration values observed and predicted during the year at each monitoring station (a total of 11 observed and 11 predicted values). This table illustrates results for the 1-hour averages, and seven models. Similar comparisons for second highest observed and predicted concentrations are presented in Table 5-6. Caution should be exercised when interpreting the meaning of some of the statistics for these rather small data sets.

The statistics provided in these tables compare observed and predicted values for 11 data pairs as shown in the first column. The next two columns present the average of the 11 observed concentrations and the average difference between observed and predicted values. The 95 percent confidence interval is given in parentheses, as calculated with a one-sample t test. As with the 25 highest concentrations, these results indicate overprediction (negative average differences), especially for COMPLEX II. At the 95 percent confidence level, the RTDM overpredictions are not significant. (The confidence interval is almost as large as the average observed value.)

The fourth column in these tables displays the fraction of positive residuals. This performance measure indicates the fraction of observed-predicted data pairs for which the observed concentration is larger than the predicted concentration. The results indicate overprediction at from 6 of 11 stations (for RTDM) to all 11 stations (COMPLEX/PFM).

The next three performance measures provide estimates of scatter, or characteristic discrepancies. They include the standard deviation of residuals (differences) with 95 percent confidence limits calculated from an F test; root mean square error; and average absolute residual. RTDM has the smallest values for all three measures, and COMPLEX II has the largest.

The Pearson correlation of observed and predicted concentration pairs and the nonparametric Spearman correlation of ranked sets of observed and predicted concentrations provide indications of the spatial correlation of the maximum concentration values at each station. Results from Table 5-5 and 5-6 show Pearson coefficients that range from 0.54 (4141 and SHORTZ) to 0.85 (COMPLEX II).

The last column in Tables 5-5 and 5-6 (variance comparison) presents the ratio of observed variance divided by the predicted variance, with 95 percent confidence bounds in parentheses as calculated by an F test. The 1-hour variance comparisons for highest and second highest by station results are significantly less than unity for all seven models, reflecting the large magnitude and range of predicted values.

TABLE 5-5

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	1859	-8939 (-14352, -3526)	.27	8058 (5630,14141)	11789	9149	.79	.74	.007 (.002, .028)
COMPLEXII	11	1859	-23851 (-35674,-12028)	.18	17600 (12297,30986)	29164	24093	.85	.74	.002 (.000, .005)
4141	11	1859	-5513 (-10353, -673)	.36	7204 (5034,12643)	8809	6165	.54	.49	.013 (.003, .036)
RTDM	11	1859	-661 (-1552, 230)	.45	1327 (927, 2329)	1428	1186	.76	.68	.171 (.045, .638)
PLUMES	11	1859	-8679 (-14375, -3384)	.18	8181 (5716,14357)	11820	9123	.76	.76	.007 (.002, .027)
COMPLEX/PFM	11	1859	-12032 (-18747, -5317)	.30	9936 (6985,17543)	15351	12033	.82	.88	.005 (.001, .018)
SHORTZ	11	1859	-6469 (-11809, -1130)	.18	7949 (5554,13750)	9965	6625	.59	.72	.008 (.002, .029)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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TABLE 5-6

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	1617	-8039 (-12784, -3294)	.27	7053 (4935,12395)	10488	8156	.75	.58	.009 (.002, .034)
COMPLEXII	11	1617	-21317 (-31857,-10776)	.18	15691 (10964,27536)	26044	21440	.83	.58	.002 (.001, .007)
4141	11	1617	-4928 (-9125, -731)	.36	6248 (4366,10965)	7732	5430	.64	.59	.012 (.003, .045)
RTDM	11	1617	-450 (-1150, 250)	.55	1043 (729, 1830)	1092	918	.75	.55	.245 (.056, .912)
PLUMES	11	1617	-7082 (-11279, -2885)	.18	6248 (4365,10964)	9255	7191	.79	.70	.012 (.003, .043)
COMPLEX/PFM	11	1617	-8250 (-12262, -4239)	.00	5971 (4172,10479)	10025	8251	.82	.58	.012 (.003, .046)
SHORTZ	11	1617	-5830 (-10667, -993)	.09	7206 (5031,12536)	9007	5864	.54	.55	.009 (.003, .035)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

Tables of statistics for 3-hour and 24-hour averages of highest and second highest observed and predicted concentrations paired by station are presented in Appendix B. The results for the longer averaging periods are very similar to those for the 1-hour averages.

Statistics for Highest Concentrations by Event

Another data set consists of the highest observed and predicted concentrations over the monitoring network for each sampling period, paired in time (i.e., one pair of values for each 1-hour, 3-hour or 24-hour sampling period). Results for the 1-hour averaging period are presented in Table 5-7. While the data sets discussed up to this point contained relatively few points, event-by-event comparisons for a full year involve much larger volumes of data (i.e., a large "N"), as shown in the first column of this table. The numbers of events is different for each model, because the number of predicted values above the threshold values of 25μg/m^3 is different. The performance measures and confidence intervals presented in this table have been discussed previously for Tables 5-1 and 5-5.

The average differences displayed in Table 5-7 indicate that six of the seven models tend to overpredict. The largest overprediction is by COMPLEX II. The average difference predicted by 4141 is not significant at the 95 percent confidence level. RTDM underpredicted by 40 percent.

The standard deviation of residuals is an indicator of the range of residual values encountered for each model. The smallest standard deviation was obtained for RTDM, and the largest for COMPLEX II. Comparisons of observed and predicted frequency distributions of concentration values ignore any time pairing between observed and predicted values. Frequency differences were significantly different from zero for all of the models. The smallest frequency difference was obtained for SHORTZ (0.247), while four of the models gave frequency differences between 0.77 and 0.82.

Tables for 3-hour and 24-hour average highest concentrations by event are provided in Appendix B. The results are generally quite similar to the results for 1-hour values. All of the models except RTDM overpredict, on average, but the differences are not significant for 4141.

Statistics for All Concentrations Paired in Time and Space

The largest data sets considered in this evaluation represent all concentration values paired in time and location. Results for the 1-hour data sets are presented in Table 5-8 (Parts 1 and 2). Due to computer work-space limitations, the size of the data sets for 1-hour values was too large to calculate the maximum difference between observed and predicted frequency distributions.

On average, three of the models overpredicted and four of the models underpredicted. All of the over-and underpredictions are significant at the 95 percent confidence level. The largest average overprediction is by COMPLEX I and COMPLEX II, and the largest average underprediction is by RTDM. The smallest average difference is by PLUMES.

TABLE 5-7

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)--
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	7173	154	-947 (-1117, -778)	3061 (3012, 3112)	.773 (.323)
COMPLEXII	7160	153	-1237 (-1441, -1033)	5073 (4992, 5158)	.769 (.323)
4141	7132	155	-36 (-73, 1)	963 (947, 979)	.305 (.323)
RTDM	7411	150	59 (46, 72)	332 (326, 337)	.316 (.322)
PLUMES	7365	152	-153 (-213, -94)	1354 (1333, 1376)	.433 (.323)
COMPLEX/PFM	7102	155	-66 (-126, -6)	1369 (1347, 1392)	.417 (.323)
SHORTZ	7785	143	-355 (-415, -315)	1297 (1277, 1317)	.247 (.322)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-8

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	30704	95	-227 (-262, -192)	1709 (1696, 1723)	****** (.011)
COMPLEXII	30682	95	-241 (-282, -200)	2535 (2515, 2555)	****** (.011)
4141	30658	95	42 (33, 50)	535 (531, 540)	****** (.011)
RTDM	32336	90	55 (51, 59)	212 (210, 214)	****** (.011)
PLUMES	31505	93	14 (1, 26)	676 (671, 681)	****** (.011)
COMPLEX/PFM	30465	95	31 (20, 43)	733 (727, 739)	****** (.011)
SHORTZ	34879	84	-82 (-94, -71)	691 (686, 596)	****** (.010)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

** VALUES COULD NOT BE CALCULATED FOR THESE VERY LARGE DATA SETS DUE TO COMPUTER WORK SPACE LIMITATIONS

TABLE 5-8 (Continued)

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.95	1724	406	.008	.115	.008 (.007, .009)
COMPLEXII	.95	2547	421	.015	.115	.004 (.003, .004)
4141	.95	537	138	.058	.095	.085 (.077, .093)
RTDM	.87	219	102	.079	-.004	.844 (.757, .928)
PLUME5	.87	676	145	.051	.069	.051 (.047, .056)
COMPLEX/PFM	.96	733	151	.009	.151	.045 (.041, .050)
SHORTZ	.70	596	206	.046	-.138	.045 (.041, .050)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

Values for standard deviation of residuals, root mean square error and average absolute residual are larger than average observed concentrations for all seven models. The largest values for all three measures occur with COMPLEX II. The smallest values of the standard deviation and root mean square error were obtained for RTDM. The smallest average absolute residual was obtained for 4141.

More than 50 percent of all residuals are positive, indicating that while all of the models tend to overpredict in terms of the average differences, there are more hours with underprediction than overprediction. COMPLEX/PFM underpredicted 96 percent of the values, while SHORTZ underpredicted 70 percent of the values.

As shown in previous studies, predicted concentrations correlate poorly with concentrations observed at the same time and place. Pearson correlations range from 0.008 (COMPLEX I and COMPLEX/PFM) to 0.079 (RTDM). Spearman correlations range from -0.138 (SHORTZ) to 0.151 (COMPLEX/PFM). Variance ratios are consistently less than 0.1 (except for 0.844 for RTDM) and significantly different from unity.

Similar results are found for the 3-hour and 24-hour average statistics for all concentrations paired in time and space (Appendix B). The same models over- and underpredict as for the 1-hour averages. Correlation coefficients improve for the 24-hour averages, but remain quite low ranging from 0.1 (COMPLEX/PFM) to 0.38 (RTDM).

Table 5-9 is presented here to exemplify the results for data subsets of observed and predicted concentrations paired in time and space. Subsets are presented by station and for various meteorological conditions. Subset tables for each of the models are presented in Appendix B. Table 5-9 shows how COMPLEX I produces a mixture of over- and underpredictions, with all overpredictions at the close-in receptors southeast of the stack. Underpredictions are noted at more distant receptors and receptors located in different directions from the plant. Overpredictions occur for all wind speed categories and for stable (E and F) conditions. Neutral and unstable hours produced underpredictions, on average.

Highest and Highest, Second-High Values

In many regulatory applications, model predictions of the highest or highest, second-high concentrations are of interest. Observed and predicted highest and highest, second-high 1-hour concentrations are presented in Table 5-10. These values clearly show an overprediction by all of the models with the largest 1-hour overprediction by COMPLEX II (nearly a factor of 20 for the highest prediction) and the smallest 1-hour overprediction by RTDM (a factor of just under two for both values). Table 5-11 shows similar results for 3-hour and 24-hour averages with the largest overpredictions again by COMPLEX II and smallest overpredictions by RTDM.

TABLE 5-9

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEXI
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	30704	95	-227	1709
STATION 1	3722	112	-589	2610
STATION 2	2247	52	51	44
STATION 3	3155	94	-302	1983
STATION 4	2423	104	-209	1742
STATION 5	2568	97	-45	998
STATION 6	3864	161	-958	3012
STATION 7	2344	106	-6	989
STATION 8	2840	76	53	383
STATION 9	2411	85	32	495
STATION 10	2364	57	16	128
STATION 11	2766	56	53	46
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	8026	130	-168	44
2.5 TO 5. M/S	15227	89	-359	44
> 5. M/S	7451	70	-20	26
2. STABILITY GROUP				
CLASS A, B & C	5867	94	86	11
CLASS D	14821	84	84	11
CLASS E	3431	86	-830	49
CLASS F	6585	125	-890	56

TABLE 5-10 - HIGHEST (H) AND HIGHEST, SECOND-HIGH (HSH) 1-HOUR CONCENTRATIONS FOR WESTVACO WITH ASSOCIATED METEOROLOGY

		1-HOUR AVERAGES			
Model		Concentration (ug/m^3)	Receptor Number	Stability Category*	Wind Speed(m/s)*
OBSERVED	H	2570	4	4	2.9
	HSH	2344	7	6	3.1
COMPLEX I	H	23678	1	6	1.2
	HSH	21063	1	6	1.3
COMPLEX II	H	50705	6	6	1.6
	HSH	46260	1	6	2.0
4141	H	18714	9	6	2.1
	HSH	18020	9	6	1.8
RTDM	H	5073	6	5	1.0
	HSH	4312	1	5	1.5
PLUME5	H	26630	7	6	1.0
	HSH	16946	1	4	4.3
COMPLEX/PFM	H	34281	4	4	1.0
	HSH	20960	1	6	1.5
SHORTZ	H	24200	6	6*	3.8
	HSH	21810	6	6*	3.3

* The SHORTZ model uses intensity of turbulence (Iy and Iz) to define dispersion. The stability categories presented here were the ones used to define meteorological subsets.

TABLE 5-11 - HIGHEST (H) AND HIGHEST, SECOND-HIGH (HSH) 3-HOUR AND 24-HOUR CONCENTRATIONS FOR WESTVACO FULL YEAR MODEL RUNS

		3-HOUR		24-HOUR	
Model		Concentration (ug/m^3)	Receptor Number	Concentration (ug/m^3)	Receptor Number
OBSERVED	H	2066	7	487	1
	HSH	1509	6	401	6
COMPLEX I	H	17973	1	4647	1
	HSH	16827	1	4102	1
COMPLEX II	H	26960	6	8854	1
	HSH	25537	6	6338	1
4141	H	10088	9	2026	9
	HSH	6238	9	1260	5
RTDM	H	2564	6	766	6
	HSH	1954	6	596	6
PLUME 5	H	15268	1	8450	6
	HSH	11901	6	3843	6
COMPLEX/PFM	H	14007	1	3024	6
	HSH	11485	4	2949	6
SHORTZ	H	10751	3	2227	3
	HSH	7605	6	1811	6

WESTVACO - IMPACT SELECT HOUR RESULTS

Performance statistics have been prepared for all models for the subset of hours selected from the Westvaco data set for IMPACT model runs. Using the criteria discussed in Section 4, a total of 20 days representing 480 hours were selected. The days selected for this analysis all contained high observed concentrations at one or more monitors, while at the same time other monitors recorded zero concentrations.

The 3-dimensional grid which was constructed for the IMPACT runs was constrained, due to computer limitations and model resolution requirements, to exclude the most distant monitor at Stony Run (receptor No. 10 in the full Westvaco model runs). Therefore the statistical comparisons for each model are based on data sets representing predictions made at 10 receptors for 480 hours (4800 receptor-hours/model).

Statistical comparisons were produced for the 1-hour, 3-hour and 24-hour averaging periods, except for the 25 highest data sets which do not contain 24-hour averages. Since only twenty 24-hour periods were analyzed, the highest by event data sets provide similar information for this averaging period.

Subsets of events by station or for various meteorological conditions are not presented for the Westvaco-IMPACT selected hour analysis.

Although the early test run package for IMPACT was approved by the model developer, the results suggest that the model did not operate properly for all prediction runs. In his review of the draft report, the model developer (Alan Fabrick) commented "the predicted concentrations are so large that they could not have occurred if the model was running correctly. For some reason the model's numerical algorithm for simulating advection and diffusion went unstable for a few hours of Westvaco simulations." The model input data for these periods of high concentrations have been reviewed along with the model code, however, to date, the specific technical problem has not been identified.

Statistics for 25 Highest Values

Table 5-12 presents statistics for the comparison of 25 highest observed and predicted SO_2 concentrations for 1-hour averages. The performance measures and confidence intervals are the same as those described for Table 5-1.

The largest overpredictions, as depicted by the difference of averages, are by COMPLEX II and IMPACT. The smallest overpredictions were obtained for 4141 and RTDM. The overpredictions are significant at a 95 percent confidence level for all models except RTDM.

Overpredictions are similarly indicated by the comparison of median differences, with two exceptions. The median differences predicted by 4141 and RTDM are not significant at the 95 percent confidence level. The IMPACT model has a much improved (but still poor) performance for this measure indicating that the average is affected by extreme overpredictions for a few hours.

TABLE 5-12

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	1792	11420	-9627 (-11043, -8212)	-8504 (-10169, -7752)	.015 (.006, .033)	1.00 (.385)
COMPLEXII	1792	20558	-18765 (-22874,-14657)	-18139 (-20821,-15630)	.002 (.001, .004)	1.00 (.385)
4141	1792	3430	-1637 (-3257, -17)	-475 (-1570, 237)	.011 (.005, .025)	.43 (.385)
RTDM	1792	2031	-238 (-810, 332)	200 (-255, 559)	.096 (.042, .217)	.35 (.385)
PLUMES	1792	5413	-3620 (-5034, -2206)	-2470 (-3835, -1617)	.015 (.006, .033)	.88 (.385)
COMPLEX/PFM	1792	9011	-7219 (-9537, -4899)	-6433 (-8785, -4617)	.005 (.002, .012)	.84 (.385)
SHORTZ	1792	7448	-5655 (-7813, -3499)	-4404 (-6864, -2151)	.006 (.003, .014)	.80 (.385)
IMPACT	1766	17829	-16042 (-26484, -5500)	-4491 (-8189, -3115)	.000 (.000, .001)	1.00 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

Again, predicted variances are large relative to observed variances. The variance ratio for RTDM (0.096) is highest, while the lowest value occurs with IMPACT (0.000).

Results for the comparison of observed and predicted frequency distributions reveal that there is very little overlap between them for most of the models. Differences between the observed and predicted distributions are shown to be significantly different from zero at the 95 percent confidence level for all models except RTDM.

Results for the 25 highest 3-hour averages (Appendix B) are quite similar to those for the 1-hour values. The main exception is that 4141 underpredicts the median difference for 3-hour values.

Statistics for Highest Concentrations at Each Station

Comparison of the sets of highest concentrations by station for the 1-hour values can be seen in Table 5-13. Results for second highest values are presented in Table 5-14. For these comparisons, each data set consists of only 10 data pairs.

Results indicate overprediction by all eight models for the highest values, and by all models except RTDM for the second highest values. However, for four models, the overpredictions are not significant at the 95 percent confidence level. The largest overpredictions occurred with the IMPACT model.

Results for the fraction of positive residuals indicate that IMPACT overpredicted the highest and second highest values at all 10 stations. PLUME5 underpredicted second highest values at 7 stations. Measures of scatter were largest for IMPACT and smallest for RTDM.

The variance comparison indicates that the variance of predicted values is significantly larger than the variance of observed values for all eight models.

Statistics for the 3-hour average and 24-hour average highest concentrations at each station are given in Appendix B. The results are similar to those for 1-hour values.

Statistics for Highest Concentrations by Event

Statistics for the comparison of highest observed and predicted concentration values event-by-event (paired in time) are provided in Table 5-15 for the 1-hour values.

The number of events (418-463), representing the number of hours analyzed for the 1-hour data sets, is less than the number of hours modeled (480) primarily as the result of screening for threshold values. Results for the average difference indicate that all of the models except 4141 and RTDM tend to overpredict the highest values each hour. However, three of the models neither over- nor underpredict significantly at the 95 percent confidence level. Large overpredictions (factor of three times observed values) occur for COMPLEX II, while the average underprediction for RTDM is about 50 percent of the average observed value.

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TABLE 5-13

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1876	-7556 (-12685, -2426)	.30	7171 (4932,13092)	10153	7767	.46	.56	.012 (.003, .049)
COMPLEXII	10	1876	-17123 (-28531, -5715)	.20	15949 (10969,29117)	21394	17253	.53	.65	.003 (.001, .011)
4141	10	1876	-3865 (-8676, 944)	.40	6725 (4625,12278)	7726	4354	.34	.32	.015 (.004, .059)
RTDM	10	1876	-164 (-1116, 787)	.70	1331 (915, 2430)	3250	893	.60	.73	.239 (.054,1.045)
PLUMES	10	1876	-3138 (-6573, 296)	.40	4802 (3303, 8767)	6076	3980	.55	.66	.025 (.005, .105)
COMPLEX/PFM	10	1876	-7520 (-13104, -1937)	.30	7806 (5369,14251)	10506	7918	.50	.64	.013 (.003, .092)
SHORTZ	10	1876	-6026 (-11029, -1023)	.10	6994 (4811,12769)	9663	6975	.59	.70	.013 (.003, .051)
IMPACT	10	1876	-43399 (-64209,-22589)	.00	29092 (20311,53115)	49131	43400	.57	.58	.001 (.000, .003)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-14

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1654	-5652 (-10085, -1220)	.20	6197 (4262,11314)	8340	5871	.53	.45	.013 (.003, .053)
COMPLEXII	10	1654	-10808 (-19398, -2217)	.40	12009 (8260,21926)	15274	11526	.45	.41	.004 (.001, .015)
4141	10	1654	-1725 (-4008, 558)	.50	3193 (2196, 5829)	4437	2350	.55	.54	.043 (.011, .181)
RTDM	10	1654	112 (-726, 951)	.60	1173 (807, 2142)	3198	932	.48	.45	.317 (.079,1.279)
PLUMES	10	1654	-588 (-3275, 2097)	.70	3756 (2584, 6858)	4577	2288	.33	.37	.035 (.009, .147)
COMPLEX/PFM	10	1654	-4490 (-9392, 411)	.40	6853 (4714,12513)	8115	5040	.52	.50	.011 (.003, .044)
SHORTZ	10	1654	-2390 (-5507, 725)	.40	4357 (2997, 7955)	5461	2779	.41	.45	.027 (.007, .107)
IMPACT	10	1654	-30198 (-45216,-15180)	.30	20995 (14441,38331)	34524	30199	.52	.54	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-15

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	460	373	-795 (-1331, -259)	3258 (3062, 3485)	.352 (.090)
COMPLEXII	461	372	-1136 (-1790, -482)	5436 (5108, 5814)	.357 (.099)
4141	461	372	128 (-27, 283)	1269 (1193, 1358)	.352 (.090)
RTDM	461	372	189 (75, 301)	682 (641, 730)	.531 (.090)
PLUMES	461	372	-135 (-457, 198)	1657 (1557, 1772)	.557 (.090)
COMPLEX/PFM	461	372	-236 (-546, 174)	2572 (2417, 2751)	.333 (.090)
SHORTZ	463	370	-323 (-599, -47)	2098 (1962, 2233)	.432 (.089)
IMPACT	418	363	-1050 (-2278, 177)	7452 (6982, 7999)	.365 (.094)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

Standard deviations of residuals indicate the largest scatter for IMPACT (20 times average observed value), with the smallest scatter by RTDM. Maximum frequency differences indicate a distinct difference among the models. For four models (COMPLEX I, COMPLEX II, 4141, and COMPLEX/PFM) there is little overlap between observed and predicted distributions, and the maximum difference is close to 1. The lowest value, for IMPACT, is 0.385.

Tables of 3-hour and 24-hour comparisons of the highest concentrations by event are displayed in Appendix B. The results are quite similar to the 1-hour comparisons. The average observed value drops rather slowly with increasing averaging time (338-349 µg/m^3 for 3-hour periods; 261-269 µg/m^3 for 24-hour periods).

Statistics for All Concentrations Paired in Time and Space

Table 5-16 (Parts 1 and 2) presents the comparison of all observed and predicted 1-hour concentration values paired in time and location for the Westvaco IMPACT select hours. The total number of events (2476-2595) implies that roughly half of the hourly observed-predicted pairs (4800 total) passed the tests for threshold and/or missing data. Average observed values are quite high (about 200 µg/m^3) due to the nature of the data selection criteria.

Results for the average differences show considerable variability among the models. From the 95 percent confidence intervals, one model overpredicts significantly (IMPACT), four models underpredict significantly (4141, RTDM, PLUME5 and COMPLEX/PFM), and three models show no significant tendency to over- or underpredict (SHORTZ, COMPLEX I and COMPLEX II). The magnitude of the average differences represents from 12-71 percent of the average observed values, except for IMPACT (343 percent). The prediction biases indicated by these results should be interpreted with caution, since the selection criteria favored hours with high observed concentrations. Results for the full data set (for all models except IMPACT) are more reliable for judging bias, because they are not subject to this limitation.

Values for the standard deviation of residuals, root mean square error and average absolute residual all exceed the average observed values. The largest measures of scatter occur for IMPACT, followed by COMPLEX II; while the smallest values occur for RTDM, and also 4141 and PLUME5.

Maximum frequency differences and fractions of positive residuals are all quite large.

Correlations of observed and predicted concentrations are extremely low, and negative in many cases. Variance ratios indicate variances for predicted values are much greater than variances for observed values.

Results for the 3-hour and 24-hour concentrations paired in time and space can be found in Appendix B. The results are generally similar to the results for 1-hour values.

TABLE 5-16

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	2477	203	-59 (-126, 11)	1638 (1594, 1685)	.358 (.039)
COMP_EXII	2476	204	-92 (-191, 6)	2471 (2404, 2542)	.358 (.039)
4141	2478	203	145 (115, 174)	724 (705, 743)	.358 (.039)
RTDM	2531	199	137 (120, 154)	409 (398, 421)	.304 (.038)
PLUMES	2508	201	100 (69, 131)	783 (762, 805)	.370 (.039)
COMPLEX/PFM	2474	204	67 (18, 117)	1267 (1232, 1303)	.343 (.039)
SHORTZ	2595	193	23 (-16, 63)	991 (965, 1019)	.743 (.038)
IMPACT	2026	183	-517 (-797, -437)	4627 (4504, 4752)	.325 (.038)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-16 (Continued)

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.97	1639	453	-.002	-.009	.041 (.037, .045)
COMPLEXII	.97	2472	488	.018	-.063	.017 (.016, .019)
4141	.97	739	230	.052	-.074	.234 (.212, .259)
RTDM	.90	431	217	.125	.058	1.180 (1.068, 1.303)
PLUME5	.92	789	269	.109	-.039	.195 (.157, .204)
COMPLEX/PFM	.96	1258	327	.017	.013	.069 (.063, .077)
SHORTZ	.82	991	306	.051	-.091	.111 (.101, .123)
IMPACT	.70	4557	872	-.020	.023	.005 (.004, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

CINDER CONE BUTTE RESULTS

All eight complex terrain models were run with the full Cinder Cone Butte data set, consisting of 104 hours of SF_6 tracer and meteorological data. Ambient tracer samples were observed at up to 94 receptor locations. Statistical performance measures were generated for the 1-hour average values, only. Results are not presented for highest concentrations by station. Otherwise, the performance measures and confidence intervals presented for Cinder Cone Butte are the same as the ones described previously for Westvaco. Slightly different subsets by meteorology and source-receptor geometry were selected for the Cinder Cone Butte analysis. All observed and predicted values and the corresponding performance measures are for relative concentrations (i.e., mass concentration per unit of emission rate, χ/Q). No screening was performed for threshold values of observed and/or predicted concentrations.

Cinder Cone Butte results for the IMPACT model did not show any evidence of the instability suspected for Westvaco. However, the model developer's comments to the draft report indicated that the eddy diffusivity algorithm in the IMPACT model is not appropriate for the grid resolution (50m horizontal; 10m vertical) used for the Cinder Cone Butte model runs. (This issue was not raised when the test package was reviewed).

Statistics for 25 Highest Values

Statistics for the comparison of 25 highest observed and predicted data sets are given in Table 5-17. From the difference of averages this table shows that six of the eight models overpredict on average, and that these differences between observed and predicted averages are non-zero at a 95 percent confidence level. The IMPACT model average underprediction is also significant at the 95 percent confidence level. Only the RTDM model shows no significant bias. Results for median difference are similar to the results for difference of averages.

Variance ratios are below 0.5 except for COMPLEX I and IMPACT. The confidence interval for COMPLEX I indicates that no significant difference exists between the variance of COMPLEX I predictions and the variance of observations at a 95 percent level of confidence.

Observed and predicted frequency distributions differ significantly for all of the models except RTDM and SHORTZ.

It should be noted that interpretation of the 25 highest observed and predicted concentrations for Cinder Cone Butte is not quite as simple as for Westvaco. This is because, in addition to the unpairing in space and time, the experiments included changes in source-receptor geometries since a mobile crane was used for the releases. One group of subsets based on source-receptor geometries was selected for investigation with the 25 highest Cinder Cone Butte data sets. Table 5-18 is presented here to exemplify the subset results for COMPLEX I. Additional subset tables are provided for all models in Appendix C. As shown in Table 5-18, the four subsets selected for the 25 highest comparisons are based on receptor height. The intention was to investigate whether model performance varied with receptor height. No pronounced differences in performance were identified.

Statistics for Highest Concentrations by Event

Comparisons of highest observed and predicted concentrations event-by-event for Cinder Cone Butte are found in Table 5-19 (Parts 1 and 2). This table is identical in form to the Westvaco tables for the full data sets paired in space and time. For this tracer data set, no threshold screening was performed. The number of events and average observed values are identified for all models.

Results for the average difference indicate overprediction by all of the models except IMPACT, which underpredicted by an average of 50 percent, and RTDM which exhibited no significant bias. The largest overprediction (by a factor of 3.6) occurred with COMPLEX II.

Measures of variability between observed and predicted concentrations (standard deviation of residuals, root mean square error and average absolute residual) are largest for COMPLEX II and smallest for IMPACT and RTDM.

The predicted frequency distributions are all significantly different from the observed distributions for all models except RTDM and SHORTZ. The largest frequency difference occurs for COMPLEX II.

From the fraction of positive residuals, COMPLEX II overpredicted for 74 percent of the highest concentrations by event, while IMPACT overpredicted for only 28 percent. The best performance for this measure was by SHORTZ which overpredicted 52 percent of the events.

Correlation coefficients for Cinder Cone Butte show some improvement over Westvaco, but remain fairly low. Pearson coefficients range from 0.26 (SHORTZ) to 0.60 (RTDM), while Spearman coefficients range from 0.32 (COMPLEX II) to 0.51 (RTDM).

The variance ratios are significantly different from unity for all the models, with the variance of predictions larger than the variance of observations for all models except IMPACT.

Table 5-20 is presented here to exemplify, for COMPLEX I, the evaluation of model performance for various subsets of source-hill characteristics and meteorological conditions. Similar tables for each model are presented in Appendix C. Six of the subsets are based on two release distance categories (less or greater than 900 m from source to butte top) and three release height categories. Wind speed and stability categories are also evaluated. The number of events in some categories is quite small.

For COMPLEX I overpredictions occurred for five of the six distance/height categories, and for low wind speeds and stable conditions. Underpredictions, on average, occurred for the higher wind speeds and non-stable conditions.

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TABLE 5-17

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEX I	66	105	-38 (-60, -15)	-31 (-56, -18)	.532 (.234, 1.207)	.52 (.383)
COMPLEX II	66	250	-183 (-231, -135)	-148 (-207, -115)	.084 (.037, .191)	.95 (.383)
4141	66	196	-129 (-158, -100)	-120 (-154, -92)	.255 (.112, .578)	.92 (.383)
RTDM	66	67	-1 (-23, 22)	5 (-12, 24)	.476 (.210, 1.080)	.23 (.383)
PLUMES	66	177	-110 (-163, -55)	-57 (-103, -45)	.062 (.027, .140)	.63 (.383)
COMPLEX/PFM	66	166	-99 (-135, -63)	-87 (-121, -57)	.151 (.067, .343)	.63 (.383)
SHORTZ	66	139	-72 (-143, -1)	-19 (-50, -3)	.037 (.016, .084)	.35 (.383)
IMPACT	66	34	31 (15, 47)	27 (13, 42)	2.645 (1.165, 6.003)	.73 (.383)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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TABLE 5-18

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEX I
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	66	105	-38 (-60, -16)	.532 (.234,1.207)
RECEPTOR ELEVATION RELATIVE TO SOURCE RELEASE HEIGHT				
<-10. M	39	64	-24	.351
-10. M TO 10. M	51	93	-41	.579
10. M TO 30. M	41	74	-32	.471
>30. M	43	59	-16	1.270

TABLE 5-19

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 1-HOUR AVERAGING PERIOD
PART 1
CINDER CONE BUTTE (1980)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	104	26	-16 (-25, -6)	41 (36, 49)	.212 (.189)
COMPLEXII	104	25	-68 (-95, -39)	103 (91, 120)	.342 (.189)
4141	104	25	-47 (-67, -26)	75 (66, 87)	.345 (.189)
RTDM	104	25	0 (-9, 9)	30 (26, 35)	.087 (.189)
PLUMES	104	25	-40 (-62, -18)	88 (78, 102)	.413 (.189)
COMPLEX/PFM	104	25	-34 (-51, -16)	66 (58, 76)	.298 (.189)
SHORTZ	104	25	-20 (-40, 0)	94 (83, 110)	.135 (.189)
IMPACT	104	25	13 (5, 20)	26 (23, 31)	.298 (.189)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-19 (Continued)

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 1-HOUR AVERAGING PERIOD
PART 2
CINDER CONE BUTTE (1980)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.43	44	29	.454	.331	.397 (.287, .550)
COMPLEXII	.25	123	74	.345	.317	.068 (.049, .094)
4141	.36	88	55	.389	.365	.125 (.090, .173)
RTDM	.53	30	19	.599	.510	.623 (.450, .864)
PLUMES	.31	96	47	.278	.439	.097 (.070, .135)
COMPLEX/PFM	.38	74	42	.305	.498	.144 (.104, .199)
SHORTZ	.48	96	35	.255	.474	.085 (.062, .119)
IMPACT	.72	29	19	.414	.397	3.238 (2.315, 4.444)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

TABLE 5-20

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: COMPLEX I
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-16	41	.454
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	-32	62	.188
H=16. M TO 26. M	12	27	-40	37	.730
H> 26. M	8	69	-19	55	.567
DISTANCE > 900. M					
H< 15. M	9	37	18	23	.649
H=16. M TO 26. M	46	19	-19	44	-.078
H> 26. M	24	13	-8	28	-.127
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	52	29	-27	47	.488
2.5 TO 5. M/S	27	22	-1	25	-.013
> 5. M/S	15	22	6	13	.464
2. STABILITY GROUP					
CLASS C+D	30	31	4	36	.529
CLASS E	38	26	-25	45	.536
CLASS F	36	22	-21	36	.381

Statistics for All Comparisons Paired in Time and Space

Statistics for the full set of paired observed and predicted concentrations are presented in Table 5-21. These data sets have the largest populations (3836 data pairs) of any group for the Cinder Cone Butte data base.

As with the high-by-event data group, average differences for all concentrations indicate overprediction by all of the models except IMPACT, which underpredicts by about 50 percent, and RTDM, which exhibits no significant bias. The largest average overpredictions are by 4141 (by a factor of over two).

Measures of variability between observed and predicted concentrations are largest for COMPLEX II, and smallest for IMPACT and RTDM. Frequency distributions of observed and predicted values are significantly different (at a 95 percent confidence level) for all eight models.

Correlation coefficients for Cinder Cone Butte model results are substantially better than for Westvaco results for all concentrations. Pearson coefficients range from 0.22 (PLUME5) to 0.43 (RTDM), while Spearman coefficients range from 0.33 (COMPLEX I) to 0.45 (SHORTZ).

The variance ratio for RTDM was not significantly different from unity (at a 95 percent level of confidence). For the other models, the variance of predictions was significantly larger than the variance of observations, although IMPACT, the opposite relationship was true.

TABLE 5-21

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
CINDER CONE BUTTE (1980)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	3836	6	-6 (-6, -5)	20 (20, 21)	.348 (.331)
COMPLEXII	3836	6	-6 (-7, -5)	34 (34, 35)	.293 (.331)
4141	3836	6	-8 (-10, -7)	30 (30, 31)	.121 (.331)
RTDM	3836	6	0 (0, 1)	13 (12, 13)	.356 (.331)
PLUMES	3836	6	-4 (-5, -3)	28 (28, 29)	.301 (.331)
COMPLEX/PFM	3836	6	-5 (-6, -4)	26 (26, 27)	.365 (.331)
SHORTZ	3836	6	-1 (-2, 0)	23 (23, 24)	.107 (.331)
IMPACT	3836	6	3 (2, 3)	12 (11, 12)	.152 (.331)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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TABLE 5-21 (Continued)

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
CINDER CONE BUTTE (1980)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.49	21	11	.359	.333	.327 (.298, .356)
COMPLEXII	.56	35	13	.236	.391	.114 (.104, .125)
4141	.42	32	14	.277	.377	.143 (.130, .157)
RTDM	.47	13	5	.425	.409	1.035 (.940, 1.139)
PLUMES	.56	28	10	.223	.409	.176 (.160, .194)
COMPLEX/PFM	.55	27	11	.313	.353	.190 (.173, .209)
SHORTZ	.49	23	7	.236	.447	.261 (.238, .287)
IMPACT	.54	12	6	.299	.422	4.521 (4.179, 5.059)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

SECTION 6

SUMMARY AND CONCLUSIONS

The performance evaluation of the complex terrain models has produced an imposing array of statistical measures to compare observed and predicted concentration values. The principal objective of this project is to produce performance statistics so that EPA and a group of reviewers may judge the relative merits of different models. In this report, the results have been discussed and explained, but no attempt has been made to compare the performance of one model versus another. Many of the model developers, upon reviewing this report, indicated the desire to see more detailed depictions of the results such as scatter plots of observed and predicted concentrations, histograms, cumulative frequency plots, isopleth analyses and time series displays. Graphical displays can be useful in exploring possible causes of poor model performance and are particularly desirable in diagnostic model evaluations. One of the difficulties encountered in the presentation of operational evaluation statistics is selecting meaningful graphical or tabular displays with limited report space. An abundance of useful information remains to be extracted from the results of this study and it is hoped that further analyses are pursued in the future. The conclusions and recommendations presented below are concerned with model evaluation methods and with the performance of the models as a group.

The complex terrain models were evaluated using two data bases representing different terrain settings and experimental approaches. The Westvaco data set consisted of one year of measurements at eleven SO_2 monitoring stations in the rugged terrain of western Maryland and northeastern West Virginia, for a buoyant tall-stack release. The Cinder Cone Butte experiments were conducted for 104 hours using a non-buoyant tracer release, with impacts measured from a 94-station sampling grid on an isolated small hill.

SUMMARY OF RESULTS

The results discussed in Section 5, plus those in Appendices B and C, contain a wealth of information concerning the performance of each of the eight complex terrain models. Distinct differences in performance are evident among the models. The patterns of results changed between the two data sets and, to a lesser extent, with averaging time (for Westvaco). A few key results are highlight below.

Westvaco. For Westvaco, seven of the models overpredicted the 25 highest concentration values for 1, 3, and 24-hour averaging times, by factors ranging from 2 to 20. RTDM predicted with less bias than the other models for all three averaging times. (The IMPACT model was evaluated only for selected hours from Westvaco.) The COMPLEX II model and the IMPACT model gave the largest overpredictions. COMPLEX I also overpredicted the average of the 25 highest 1-hour values by almost a factor of 10.

Cinder Cone Butte. Six of the eight models overpredicted the 25 highest 1-hour values. IMPACT underpredicted, and RTDM predicted with no significant bias. COMPLEX II again gave the largest overprediction, roughly a factor of 4 times observed.

Thus, COMPLEX II showed the most consistent and pronounced tendency to overpredict peak concentrations; RTDM showed the least bias for estimating peak 1-hour values; and IMPACT showed the greatest inconsistency between the two data sets.

Model performance results for the two data sets showed several striking differences:

- The models showed a much greater tendency to overpredict peak 1-hour concentrations for the Westvaco data set than for Cinder Cone Butte.

- Comparisons between predicted and observed concentrations, paired in time and location, showed smaller discrepancies and higher correlation for Cinder Cone Butte than for Westvaco.

- For Westvaco, model performance was very different for stable and neutral conditions (for most of the models). For Cinder Cone Butte, model performance was generally similar for both stability categories.

These differences point to the importance of the source characteristics and the local terrain setting (as well as other design factors) for model performance in complex terrain.

The Westvaco data set permitted model performance to be evaluated by monitoring station and for several averaging times. From these analyses, the following conclusions could be drawn:

- Distinct differences in model performance were found between those monitors within 2 km of the plant and those at greater distances. Overprediction was more pronounced at monitors close to the plant.

- Results for 1-hour and 3-hour averages were quite similar. For 24-hour averages, however, distinct differences in model performance were found for estimating peak concentrations.

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APPENDIX A

TEST RUN PACKAGE: DESCRIPTION OF MODELS "AS-RUN" FOR COMPLEX TERRAIN MODEL EVALUATION

TEST RUN PACKAGE:
DESCRIPTION OF MODELS "AS-RUN"
FOR COMPLEX TERRAIN MODEL EVALUATION

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1.0 INTRODUCTION

EPA has contracted with TRC to evaluate the performance of complex terrain air quality simulation models using performance measures recommended by the American Meteorological Society. Eight models are to be evaluated: COMPLEX-I, COMPLEX-II, PLUME5, RTDM, SHORTZ, 4141, COMPLEX/PFM, and IMPACT. Prrior to running the complex terrain models for evaluation, it is desireable to confirm that the models have been implemented in accordance with the expectations of the model developers. To accomplish this, test-run packages were prepared and are being supplied to the model developers for their formal review and concurrence. The package supplied to each model developer contains the following information:

- Descriptions of the complex terrain model evaluation data bases (Cinder Cone Butte and Westvaco);
- Summary of model-code modifications;
- Summary of input options;
- Test-run data (listings of all input and output data) for the model developer's particular model;
- Complete listing of the model code "as run," (for the model developer's particular model) to enable the model developer to confirm the code line-by-line.

Also provided as part fo the test case package are three other relevant documents:

- "Data Archiving Recommendations for Complex Terrain Model Evaluations" (TRC, November 1982).
- "Addendum to: Data Archiving Recommendations for Complex Terrain Model Evalutions (Response to Comments from Model Developers)" (TRC, July 1983).
- "Statistical Evaluation for Complex Terrain Models" (TRC, June 1983).

This document summarizes the model code modifications made by TRC and input options selected by the model developers for each model and data base. Modifications to the models were needed for three basic reasons:

- To adapt the model to the EPA UNIVAC computer.
- To adopt particular models to accept the source-receptor inventories.
- To format calculated concentrations for input to the statistics system.

Detailed summaries of line-by-line changes made by TRC to each model's computer code are also described in this document.

Computer code listings for the models "as run," plus the test run input and output data listings are supplied separately.

2.0 COMPLEX-I AND COMPLEX-II

2.1 Technical Modifications to COMPLEX-I and COMPLEX-II

TRC altered COMPLEX-I and COMPLEX-II to accept input data from the model input file on Unit 18 rather than Unit 5. Statements were added to facilitate writing calculated concentrations to a work file for future statistical analysis. These changes were made for both the Westvaco and Cinder Cone Butte data bases.

To accommodate the Westvaco data base, TRC modified COMPLEX-I and COMPLEX-II in three areas. The models were altered to accept hourly input of source exit velocity and exit temperature. TRC made changes to circumvent problems that could be caused by the Westvaco data starting in one calendar year and ending in the next calendar year. Code was added to check for hours with missing stability during which no concentrations were calculated.

When COMPLEX-I and COMPLEX-II were tested with the Cinder Cone Butte data base, one technical modification was needed. The models were altered so that only the source with a source number (1-111) equal to the hour (1-111) being modeled has an impact on the calculated concentrations. This modification, consistent with the input emissions inventory, was needed because a single emission point was moved each hour in the Cinder Cone Butte study.

2.2 COMPLEX-I and COMPLEX-II: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	1	No stack downwash.
IOPT(3)	1	No gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
IOPT(25)	1	Use complex terrain option.
HANE	0.90	Anemometer height in meters.
PL	0.,0.,0.,0.,0.,0.	Wind profile power law exponents.
CONTER	0.5,0.5,0.5,0.5,0.,0.	Terrain adjustment factors.
ZMIN	10.	Distance limit for plume centerline from ground.
HAFL	0.	No pollutant loss.

2.3 COMPLEX-I and COMPLEX-II: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	0	Use stack downwash.
IOPT(3)	1	No gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
IOPT(25)	1	Use complex terrain option.
HANE	189.7	Anemometer height in meters.
PL	0.,0.,0.,0.,0.,0.	Wind profile power law exponents.
CONTER	0.5,0.5,0.5,0.5,0.,0.	Terrain adjustment factors.
ZMIN	10.	Distance limit for plume centerline from ground.
HAFL	0.	No pollutant loss.

2.4 TRC Changes to COMPLEX-I for Cinder Cone Butte

Line Number	Description of Modification
1-2, 134-137	Comments.
358-360	Dimension TRC variables.
377-381	Define work file.
451-455, 466-475	Initialize I/O units and hour counter. Check data base ID.
736-740	Do not read met station identifiers.
945-948	Increment the TRC hour counter.
1061-1064, 1568-1570	Transfer TRC hour counter to subroutine PTR.
1065-1074	Write to hourly work file.
1617-1619	Ignore sources other than the one which corresponds to the hour of simulation.
1702-1703	Set distance to final plume rise equal to zero.
1734	Allow for stack temperature equal to ambient.

2.5 TRC Changes to COMPLEX-I for Westvaco

Line Number	Description of Modification
1-3, 135-138, 472	Comments.
359-362	Dimension TRC variables.
379-384	Define work file.
454-462, 474-485	Initialize I/O units. Check data base ID.
900-905, 910-912, 917-919, 924-931, 934-936, 1084-1087, 1482-1483	Changes to accommodate data from two calendar years.
978-987	Flag missing stability data.
1088-1101, 1722-1726	Read in hourly source data.
1108-1118	Write to work file.

2.6 TRC Changes to COMPLEX-II for Cinder Cone Butte

Line Number	Description of Modification
1-2, 132-135	Comments.
356-358	Dimension TRC variables.
375-379	Define work file.
449-454, 465-474	Initialize I/O units and hour counter. Check data base ID.
735-749	Do not read met station identifiers.
943-946	Increment the TRC hour counter.
1059-1062, 1565-1567	Transfer TRC hour counter to subroutine PTR.
1063-1071	Write to hourly work file.
1614-1616	Ignore sources other than the one which corresponds to the hour of simulation.
1699-1700	Set distance to final plume rise equal to zero.
1731	Allow for stack temperature equal to ambient.

2.7 TRC Changes to COMPLEX-II for Westvaco

Line Number	Description of Modification
1-3, 133-136, 465	Comments.
357-359	Dimension TRC variables.
376-381	Define work file.
451-455, 467-478	Initialize I/O units. Check data base ID.
893-897, 902-904, 909-911, 921-923, 926-928, 1077-1079, 1472-1473	Changes to accommodate data from two calendar years.
970-980	Flag missing stability data.
1080-1091, 1712-1716	Read in hourly source data.
1098-1108	Write to work file.

3.0 PLUME5

3.1 Technical Modifications to PLUME5

TRC added code to PLUME5 to write calculated concentrations to a work file for future statistical analysis. The model was altered to allow input from a disk file rather than cards. The meteorological data input unit has been set to 11. To reduce computer core requirements, receptor arrays dimensioned by 500 were reduced to the number of receptors in each respective data base.

For the Westvaco data base only, TRC modified PLUME5 to accept hourly values of emission rate, stack exit velocity, and stack exit temperature.

Several changes were made to adapt PLUME5 to the Cinder Cone Butte data base. Code was added to skip the reading of station identifiers on the disk file containing meteorological data and to read the meteorological data one hour at a time. The DO loops on days and hours were merged into a single loop to handle the non-sequential nature of the Cinder Cone Butte experiment hours. Daily and annual average output were skipped. Plume rise was set equal to zero. TRC also modified the model so that only the source with a source number equal to the consecutive hour number has an impact on calculated concentrations (See Section 2.1).

3.2 PLUME5: Input Options and Variables

Variable Name	Input Value		Description
	Westvaco	CCB	
CONVRT (PLUME5 preprocessor):			
ISTAT	2	2	Stability classified by σ_A.
MST	1	1	Modify unstable stability at night as a function of wind speed.
DTHDZ	0.01	0.01	Default value for change of potential temperature with height through stable layer.
THICK	800.	NA	Default value for the thickness of stable layer.
SIGMAF	1	1	Default multiplier for sigma value.
LAT	39.5	43.0	Latitude of surface station.
LONG	79.3	115.5	Longitude of surface station.
ZONE	5	7	Standard time zone.
NCCOFF	0	NA	NCC mixing height data used.
PLUME5:			
IUR	1	1	RURAL1 mixing heights used.
BKGRD	1.E-30	1.E-30	Background concentration in $\mu g/m^3$.
IGRID	0	0	Do not use receptor grid.
ICIRC	0	0	Do not generate receptors using radial rings.
IATOB	1	1	Changes Class A stability to Class B.
IPLUME	0	0	No hourly plume rise input.
ISGFLG	1	1	Initial plume expansion allowed.
MODFLG	1	1	Pasquill modification to the crosswind spread of plumes due to vertical wind directional shear allowed.
WINDHT	189.7	10.	Wind speed measurement height (meters).
MSLFLG	1	NA	Mixing heights are above ground level.

3.3 TRC Changes to PLUMES Code for Cinder Cone Butte

General: Receptor array arguments reduced from 500 to 94 to reduce core requirements. The number of point source locations was raised from 10 to 111, while the number of release heights per location was reduced from 15 to 1. One source per hour of simulation. Mixing height set to 9999 meters.

Line Number	Description of Modification
1-13	Comments.
26-28, 523-524	Define TRC COMMON block.
47-60	Initialize I/O units. Define work file. Check data base ID.
84	Change loop on sources from 10 to 111.
117-119, 138-139	Skip section which reads station identifiers from meteorlogical data file.
145-146, 1402-1403	Change maximum number of sources allowed.
150-151	Change maximum number of heights per source.
178-180, 480-481, 485-486	Change write statement.
521-522	Dimension TRC variables.
552-554	Reduce maximum number of receptors allowed from 500 to 94.
628-636, 723, 728-730	Change the day and hour loops since CCB data is not in 24 hour groups.
651-652	Change unit number for input of meteorological data.
656-672	Read in the meteorological data, one hour at a time.
694-714	Change write statement and format for output of meteorological data.
766-769, 857	Separate the loops on source location and release height.

3.3 TRC Changes to PLUME5 Code for Cinder Cone Butte (Continued)

Line Number	Description of Modification
770-773, 889-893	Ignore sources other than the one which corresponds to the hour of simulation.
1211-1220	Write to the work file.
1222-1226	Skip output of daily and annual averages.
1855-1857	Set plume rise to zero.

3.4 TRC Changes to PLUME5 Code for Westvaco

General: Receptor array arguments reduced from 500 to 11 to reduce core requirements.

Line Number	Description of Modification
1-5	Comments.
18-20, 515-517	Define TRC common block.
39-60	Initialize I/O units. Define work file. Check data base ID.
119-123, 638-642	Change unit number for input of meteorological data.
511-514	Dimension TRC variables.
545-549	Change maximum number of receptors allowed from 500 to 11.
691-700	Read and print the hourly point source data.
1167-1173	Write to the work file.

120<

4.0 RTDM

4.1 Technical Modifications to RTDM

TRC made general and data base specific modifications to RTDM. For both the Westvaco and Cinder Cone Butte data bases, code was added to write calculated concentrations to a work file, and to read model input data on Unit 18 rather than Unit 5. Meteorological data is read from Unit 10 for Cinder Cone Butte, and Units 10 and 11 for Westvaco, instead of Unit 7. For both data bases, assignment of the PR005 parameter has been fixed to properly correspond to wind profile exponents, not terrain factors.

Modifications specific to the Westvaco data base include reading hourly source data from Unit 15, reading meteorological station identifiers from Unit 10, and checking for hours with missing stability. Concentrations are not calculated for the hours with missing stability.

For the Cinder Cone Butte data base, RTDM was modified to set plume rise and wind profile exponents equal to zero, to set anemometer height equal to release height, and to allow hours which are out of sequence. TRC modified RTDM so that only one source contributes to the calculated concentration in any given hour (See Section 2.1).

4.2 RTDM: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description
ZWIND1	Release height	Anemometer height (m).
ZWIND2	Not used	
IDILUT	0	Wind speed at level 1 is used for plume rise and transport calculations.
EXPON	0.,0.,0.,0.,0.,0.	Wind speed profile power law exponents.
ICOEF	3	ASME (1979) stability-dependent dispersion parameters.
IPPP	0	No partial plume penetration.
IBUOY	1	Use buoyancy-enhanced dispersion.
IALPHA	3.162	
IDMX	1	Unlimited mixing height in stable conditions.
ITRANS	1	Use transitional plume rise.
TERCOR	0.5,0.5,0.5, 0.5,0.5,0.5	Plume path correction factors.
RVPTG	0.02, 0.035	Default VPTG for stabilities 5 and 6.
ITIPD	0	No stack-tip downwash.
IY	1	User-supplied I_y.
IZ	1	User-supplied I_z.
IRVPTG	0	Default VPTG for plume rise calculations.
IHVPTG	1	User-supplied VPTG for H_{crit} calculations.
ISHEAR	0	Wind direction shear is not used in σ_y computation.
IEPS	0	No hourly wind profile exponents.
IREFL	1	Use partial reflection algorithm.
IHORIZ	1	Off-centerline horizontal distribution function.
IEMIS	0	Use constant emission rate.

4.3 RTDM: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
ZWIND1	30.	Anemometer height (m) above ZA, for plume rise.
ZWIND2	Not used	Anemometer height for transport.
IDILUT	0	Wind speed at level 1 extrapolated to stack top for plume rise calculations and to plume height for transport calculations.
ZA	179.6	Height above stack base where the wind profile originates.
EXPON	0.,0.,0.,0.,0.,0.	Wind speed profile power law exponents.
ICOEF	3	ASME (1979) stability-dependent dispersion parameters.
IPPP	0	No partial plume penetration.
IBUOY	1	Use buoyancy-enhanced dispersion.
IALPHA	3.162	
IDMX	1	Unlimited mixing height in stable conditions.
ITRANS	1	Use transitional plume rise.
TERCOR	0.5,0.5,0.5, 0.5,0.5,0.5	Plume path correction factors.
RVPTG	0.02, 0.035	Default VPTG for stabilities 5 and 6.
ITIPD	1	Use stack-tip downwash.
IY	1	User-supplied I_y.
IZ	1	User-supplied I_z.
IRVPTG	1	User-supplied VPTG for plume rise calculations.
IHVPTG	1	User-supplied VPTG for H_{crit} calculations.
ISHEAR	1	Wind direction shear is used in σ_y computation.

4.3 RTDM: Input Options and Variables for Westvaco
(Continued)

Variable Name	Input Value	Description
IEPS	1	User-supplied hourly wind profile exponents.
IREFL	1	Use partial reflection algorithm.
IHORIZ	1	Off-centerline horizontal distribution function.
IEMIS	1	User-supplied hourly emission rate.

4.4 TRC Changes to RTDM for Cinder Cone Butte

Line Number	Description of Modification
1-4	Comments.
21	Define work file.
22-32	Check data base ID.
33-41	Read and print the experiment hours being modeled.
474-475	PR005 should read wind profile exponents, not terrain factors.
1177-1178	Change requested by ERT.
1365-1367, 1695-1696	Define TRC common block.
1436-1448, 1452-1453	Read meteorological data.
1463-1464	Allow hours which are out of sequence.
1510-1514, 1546-1547, 1549-1550, 1583-1586	Change output formats.
1697-1698	Dimension TRC variables.
1712-1717	Allow source contribution from only one source per hour.
1738-1734	Set wind profile exponents equal to zero and wind measurement height equal to release height.
1759, 1763	Set plume rise equal to zero.
1836, 1850-1856	Write to the work file.

4.5 TRC Changes to RTDM for Westvaco

Line Number	Description of Modification
1-4	Comments.
21	Define work file.
22-34	Check data base ID.
35-36	Read station identifiers from meteorological data file.
471-472	PR005 should be reading wind profile exponents, not terrain factors.
1175-1176	Change requested by ERT.
1365-1374, 1736-1739	Define TRC common block.
2891	Dimension TRC variables.
1443-1475, 1479, 1485-1486	Read meteorological data from two files.
1480-1484, 1742-1748, 2897-2902	Flag hours with missing stability.
1491-1507	Read point source data file.
1610-1618, 1624-1627	Change error message formats.
1871-1874, 1887-1893	Write to work file.

5.0 SHORTZ

5.1 Technical Modifications to SHORTZ

The SHORTZ model was modified to accept input data from a disk file, and to write calculated concentrations to a work file for subsequent statistical analysis. For the Westvaco data base run, an hour counter and an alternate output format for the time period in question were added. Modifications specific to the Cinder Cone Butte data base include setting plume rise equal to zero, adding an array to hold calculated concentrations, and allowing the maximum number of hours in a case to equal 111.

5.2 SHORTZ: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description
ISW(7)	1	Terrain elevation data are input.
ISW(9)	0	Wind speed is not terrain following.
ISW(17)	0	Rural option.
G	9.80	Acceleration of gravity (m/s^2).
ZR	9.99	Wind speed measurement height (m).
GAMMA1	0.60	Entrainment coefficient for unstable atmosphere.
GAMMA2	0.66	Entrainment coefficient for stable atmosphere.
XRY	50.	Distance (m) over which rectilinear expansion occurs downwind of source.
DECAY	0.	No pollutant loss.
HA	99.9	Elevation (m) of base of weather station.

5.3 SHORTZ: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
ISW(7)	1	Terrain elevation data are input.
ISW(9)	0	Wind speed is not terrain following.
ISW(17)	0	Rural option.
G	9.80	Acceleration of gravity (m/s^2).
ZR	30.0	Wind speed measurement height (m).
GAMMA1	0.60	Entrainment coefficient for unstable atmosphere.
GAMMA2	0.66	Entrainment coefficient for stable atmosphere.
XRY	50.	Distance (m) over which rectilinear expansion occurs downwind of source.
DECAY	0.	No pollutant loss.
HA	467.6	Elevation (m) of base of weather station.

5.4 TRC Changes to SHORTZ for Cinder Cone Butte

Line Number	Description of Modification
2-14, 118-135	Comments.
26-55, 656-684	Define TRC COMMON block EVAL.
86-94	Initialize I/O units.
98-114	Define work file.
136-171	Check data base ID.
202-210	Set TRC variable NMON=NXXYY.
232	Set MKQ=111, maximum number of hours.
1194-1199	Zero the TRCONC array each hour.
1211	Let maximum number of hours = 111.
1483-1488	Set plume rise equal to zero.
1797-1802	Put calculated concentrations into array TRCONC.
1812-1834	Write to the work file.

5.5 TRC Changes to SHORTZ for Westvaco

Line Number	Description of Modification
2-14, 118-135	Comments.
26-55, 656-684, 2043-2048	Define TRC COMMON block EVAL.
86-94, 154	Initialize I/O units.
98-114	Define work file.
136-171	Check data base ID.
202-210	Set TRC variable NMON=NXXYY.
1795-1817	Write to work file.
1875-1876	Set hour counter IHRTRC.
2120-2125	Change the output hour format.

6.0 4141

6.1 Technical Modifications to 4141

Modifications to 4141 are the same as for COMPLEX-I and COMPLEX-II.

6.2 4141: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description
MODEL	4141	Select 4141 Model Option. Sets CONTER = 0.5,0.5,0.5,0.5, 0.25,0.25. Sets IOPT(4) = 1. Sets IOPT(1) = 1.
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	1	No stack downwash.
IOPT(3)	0	Gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
HANE	0.9	Anemometer height in meters.
PL	0.,0.,0.,0.,0.,0.	Wind speed profile power law exponents.
HAFL	0.	No pollutant loss.

6.3 4141: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
MODEL	4141	Select 4141 Model Option. Sets CONTER - 0.5,0.5,0.5,0.5, 0.25,0.25. Sets IOPT(4) = 1. Sets IOPT(1) = 1.
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	1	No stack downwash.
IOPT(3)	0	Gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
HANE	189.7	Anemometer height in meters.
PL	0.,0.,0.,0.,0.,0.	Wind speed profile power law exponents.
HAFL	0.	No pollutant loss.

6.4 TRC Changes to 4141 for Cinder Cone Butte

Line Number	Description of Modification
1-2, 82-85, 185-188	Comments.
304-306	Dimension TRC variables.
325-329	Define work file.
404-409, 421-430	Initialize I/O units and hour counter. Check data base ID.
689-692	Do not read met station identifiers.
899-902	Increment the TRC hour counter.
1015-1018, 1597-1599	Transfer TRC hour counter to subroutine PTR.
1019-1028	Write to hourly work file.
1645-1647	Ignore sources other than the one which corresponds to the hour of simulation.
1729-1731	Set distance to final plume rise equal to zero.
1761-1762	Allow for stack temperature equal to ambient.

6.5 TRC Changes to 4141 for Westvaco

Line Number	Description of Modification
1-3, 83-86, 186-189	Comments.
305-307	Dimension TRC variables.
326-331	Define work file.
406-410, 423-434	Initialize I/O units. Check data base ID.
848-853, 858-860, 865-867, 872-879, 882-884, 1033-1035	Changes to accommodate data from two calendar years.
926-936	Flag missing stability data.
1036-1047	Read in hourly source data.
1054-1064	Write to work file.

7.0 COMPLEX/PFM

7.1 Technical Modifications to COMPLEX/PFM

The technical modifications to COMPLEX/PFM consist of the same changes made to COMPLEX-I and COMPLEX-II, plus several alterations specific to COMPLEX/PFM. For both the Westvaco and Cinder Cone Butte data bases, COMPLEX/PFM was modified to read receptor data from a unique disk file. Also, array sizes were reduced in accordance with data base requirements in order to reduce the need for computer core storage.

Some modifications were needed only for the Cinder Cone Butte data base. These include reading the potentially non-sequential list of experiment hours to be modeled; reading hourly values of critical streamline height (Hcrit)and Froude number from a disk file; and accounting for the absence of vertical wind and temperature profiles in the Cinder Cone Butte input data set.

7.2 COMPLEX/PFM: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	1	No stack downwash.
IOPT(3)	1	No gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
IOPT(25)	1	Use complex terrain option.
IOPT(26)	1	Long-term PFM option.
HANE	0.90	Anemometer height in meters.
PL	0.,0.,0.,0.,0.,0.	Wind profile power law exponents.
CONTER	0.5,0.5,0.5,0.5,0.,0.	Terrain adjustment factors.
ZMIN	10.	Distance limit for plume centerline from ground.
HAFL	0.	No pollutant loss.

7.3 COMPLEX/PFM: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
IOPT(1)	1	Use terrain adjustments.
IOPT(2)	0	Use stack downwash.
IOPT(3)	1	No gradual plume rise.
IOPT(4)	1	Calculate initial plume size.
IOPT(25)	1	Use complex terrain option.
IOPT(26)	1	Long-term PFM option.
HANE	189.7	Anemometer height in meters.
PL	.10,.15,.20,.25,.25,.25	Wind profile power law exponents.
CONTER	0.5,0.5,0.5,0.5,0.,0.	Terrain adjustment factors.
ZMIN	10.	Distance limit for plume centerline from ground.
HAFL	0.	No pollutant loss.

7.4 TRC Changes to COMPLEX/PFM for Cinder Cone Butte

Line Number	Description of Modification
1-18, 183-186, 314-316, 373-374, 429-430, 602, 2322, 4141-4142, 5960-5961.	Comments.
453-455, 2323-2327, 5495-5497	TRC common block definition .
458-460	Dimension TRC variables.
484-489	Define work file.
569-573, 4172-4175	Change the maximum number of receptors from 180 to 99 to reduce core requirements.
582-587	I/O device initialization.
604-625	Read and verify data base and work file identifiers. Read in the experiment hours to be modeled.
920-923, 1258-1264, 1298-1299	Modifications to account for the absence of wind and temperature profiles.
1141-1147	Read Hcrit and Froude number from TRC disk file.
1318-1328	Write calculated concentrations to work file.
1887	Write format change.
2423-2426	Print Hcrit and Froude number.
5549-5552, 5581-5584, 5856-5858	Do not call subroutines which calculate Hcrit and Froude number.
5607-5612	Allow source contributions from only one source per hour.
5714-5716, 5747-5748	Allow for ambient temperature identical to stack temperature.
6005-6010	Change format and input unit of statements which read receptor data.

7.5 TRC Changes to COMPLEX/PFM for Westvaco

Line Number	Description of Modification
1-11, 176-179, 307-309, 366-367 422-423, 592, 5933-5934	Comments.
448-450	Dimension TRC variables.
474-479	Define files.
559-563, 4166-4169	Change maximum number of receptors allowed from 180 to 15 to reduce computer core requirements.
572-577	Device initializations.
594-605	Read and verify data base and work file identifiers.
1064-1068, 1073-1075, 1080-1082, 1087-1094, 1098-1100, 1297-1298	Changes to accommodate data from two calendar years.
1142-1152	Check for missing stability. Set calculated concentration to missing.
1299-1311, 5659-5663	Read hourly point source data.
1318-1329	Write calculated concentrations to the work file.
5978-5983	Change format of statements which read receptor data.

8.0 IMPACT

8.1 Technical Modifications to IMPACT

TRC inserted additional codes within specific sections of the IMPACT model to produce the following two results:

i) Identify and write to the output work file those 1-hour average surface level concentrations for calls corresponding to monitor sites. These changes were included for both the Westvaco and Cinder Cone Butte versions of the model.

ii) Redimension arrays in the COMMON block TREFOR to accommodate the number of cells utilized in the X-, Y-, and Z- directions for each data base. In the case of Westvaco, the number of cells are 13, 15, and 20, respectively, with corresponding cell dimensions of 200, 200, and 60.96m. In the case of Cinder Cone Butte, the number of cells are 36, 45 and ~~14~~, respectively, with corresponding cell dimensions of 50m, 50m ↑ 20 and 10m. 1/84

The IMPACT model allows for a maximum of 40 cells in the "X-" direction. The actual grid developed by TRC for Cinder Cone Butte contains 45 cells in the East-West direction. In order to avoid additional code revisions, the grid was rotated 90° counter-clockwise. There are now 36 cells in the X- direction (north-south) and 45 cells in the Y- direction (east-west).

Another modification to the IMPACT model was required for the Cinder Cone Butte application. The minimum time step, DTMIN (specified in a Data statement located in subroutine DIFFUS), was reduced from 3.6 seconds to ~~1.0~~ 0.5 seconds. This change allows the model to calculate a time step appropriate for the small grid spacing defined for Cinder Cone Butte. 1/84

8.2 IMPACT: Input Options and Variables for Cinder Cone Butte

Variable Name	Input Value	Description	
DX	50.	E-W cell size in m.	
DY	50.	N-S cell size in m.	
DZ	~~10.~~ 7.5	Vertical cell size in m.	1/84
NX	36	Number of grid cells in x-direction	
NY	45	Number of grid cells in y-direction	
NZ	~~15~~ 20.	Number of grid cells in z-direction	1/84
IDOWND	1	WEST wind Model	
IDOCEM	1	1 tracer effluent	
IDOPLM	1	User specified ΔH for plume rise (ΔH=0.)	
IDODIF	3	DEPICT algorithm diffusivities	
IDOBAK	1	User specified background (background =0.)	
NUMHRS	1	Number of hours to be modeled	
IDOPLT	0	No contour plots	
IDOPRN	1	Printer edit every hour for test run	
IDOCAL	0	No CALCOMP plots	
HRSAUG	1	Hourly printout for test run	
IDOSUR	0	Hourly printout for vertical levels	

8.3 IMPACT: Input Options and Variables for Westvaco

Variable Name	Input Value	Description
DX	200.	E-W cell size in m.
DY	200.	N-S cell size in m.
DZ	60.96	Vertical cell size in m.
NX	13	Number of grid cells in x-direction
NY	15	Number of grid cells in y-direction
NZ	20	Number of grid cells in z-direction
IDOWND	1	WEST wind model
IDOLEM	1	1 tracer effluent
IDOPLM	0	Briggs' '74 Plume Rise
IDODIF	3	DEPICT algorithm diffusivities
IDOBAK	1	User specified background set to 0.0
NUMHRS	25	Number of hours to be modeled
IDOPLT	0	No contour plots
IDOPRN	1	Printer edit every hour for test run
IDOCAL	0	No CALCOMP plots
HRSAUG	1	Hourly printout for test run
IDOSUR	1	Print surface values only

8.4 TRC Changes to IMPACT (Version 1 from Radian) for Cinder Cone Butte

Line Number	Description of Modification
1-18	Comments
113-130, 386-402, 898-915, 998-1014, 1325-1341, 1735-1751, 1975-1991, 2180-2196, 2569-2585, 2813-2829, 2962-2978, 3069-3085, 3145-3161	Common TREFR1, TREFR2
131-265	Comments, TRC COMMON verify input files, load I, J of receptors
2197-2224	TRC COMMON
2230-2239	DTMIN, minimum time step, set to 1.0 sec.
2481-2514	Write to work file

8.5 TRC Changes to IMPACT (Verion 1 from Radian) for Westvaco

Line Number	Description of Modification
1-18	Comments
113-124, 381-392, 888-900, 983-994, 1305-1316, 1710-1721, 1945-1956, 2145-2152, 2531-2542, 2770-2781, 2914-2925, 3016-3027, 3087-3098	Common TREFOR
125-260	Comments, TRC COMMON, verify input files, load I, J of receptors
1969-1984	Set unset variable
2153-2186	TRC COMMON
2443-2476	Write to work file

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APPENDIX B

STATISTICAL TABLES OF MODEL PERFORMANCE FOR WESTVACO

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COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	1969	18169	-16199 (-17149,-15249)	-15872 (-17144,-14542)	.017 (.008, .039)	1.00 (.385)
COMPLEXII	1969	38638	-36669 (-38555,-34782)	-35616 (-37307,-33968)	.004 (.002, .010)	1.00 (.385)
4141	1969	12205	-10236 (-11549, -8922)	-9558 (-11689, -8080)	.009 (.004, .020)	1.00 (.385)
RTDM	1969	3289	-1319 (-1652, -985)	-655 (-945, -282)	.151 (.057, .344)	.92 (.385)
PLUMES	1969	14525	-12556 (-13923,-11188)	-11472 (-12831,-10748)	.008 (.004, .019)	1.00 (.385)
COMPLEX/PFM	1969	15163	-13193 (-15397,-10989)	-11389 (-12329,-10520)	.003 (.001, .007)	1.00 (.385)
SHORTZ	1969	13563	-11594 (-13075,-10112)	-10153 (-11021, -9576)	.007 (.003, .016)	1.00 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

```
                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                     SO2 CONCENTRATION VALUES (UG/M**3)
                       (UNPAIRED IN TIME OR LOCATION)
                           FOR VARIOUS DATA SETS
                             MODEL: COMPLEXI
                     FOR THE  1-HOUR AVERAGING PERIOD
                            WESTVACO (1980/1981)

---------------------------------------------------------------------------------------------

        DATA SETS            AVERAGE         AVERAGE         DIFFERENCE         VARIANCE
                             OBSERVED        PREDICTED       OF AVERAGES*       COMPARISON
                             VALUE           VALUE           (OBS-PRED)         (OBS/PRED)

---------------------------------------------------------------------------------------------

        ALL                      1969           18169              -16199              .017
                                                          (-17149,-15249)      ( .008, .039)

        STATION  1               1316           16574              -15257              .013
        STATION  2                318              43                 276            11.967
        STATION  3               1112           12369              -11257              .264
        STATION  4               1072           12089              -11015              .029
        STATION  5               1374            8104               -6729              .176
        STATION  6               1411           15372              -13960              .029
        STATION  7               1347            8398               -7050              .024
        STATION  8               1103            2354               -1250              .032
        STATION  9               1183            4422               -3238              .056
        STATION 10                339             428                 -88            30.642
        STATION 11                315             191                 124              .754

---------------------------------------------------------------------------------------------

        METEOROLOGICAL CONDITION

        1. WIND SPEED
           < 2.5 M/S             1576           18169              -16592              .023
           2.5 TO 5. M/S         1813           12828              -11013              .801
           > 5. M/S               551            6664               -6111              .023

---------------------------------------------------------------------------------------------

        2. STABILITY GROUP
           CLASS A, B & C        1092             419                 674             7.232
           CLASS D               1517               8                1509         12133.506
           CLASS E               1118           11859              -10741              .114
           CLASS F               1667           18169              -16501              .027
```

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                         SO2 CONCENTRATION VALUES (US/M**3)
                           (UNPAIRED IN TIME OR LOCATION)
                              FOR VARIOUS DATA SETS
                                 MODEL: COMPLEXII
                        FOR THE  1-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)
--------------------------------------------------------------------------------------------
         DATA SETS             AVERAGE          AVERAGE          DIFFERENCE         VARIANCE
                              OBSERVED         PREDICTED        OF AVERAGES*       COMPARISON
                                VALUE            VALUE           (OBS-PRED)        (OBS/PRED)
--------------------------------------------------------------------------------------------

         ALL                    1959            38638              -36658              .004
                                                            (-38555,-34782)      ( .002, .010)

         STATION  1             1316            35157              -33840              .003
         STATION  2              318               39                 279            34.062
         STATION  3             1110            24983              -23872              .002
         STATION  4             1372            23135              -22051              .004
         STATION  5             1374             9890               -8515              .003
         STATION  6             1411            32664              -31252              .009
         STATION  7             1347            11575              -10228              .001
         STATION  8             1105             2519               -1414              .007
         STATION  9             1183             5253               -4068              .004
         STATION 10              339             1722               -1382              .369
         STATION 11              315              140                 174             1.965
--------------------------------------------------------------------------------------------

         METEOROLOGICAL CONDITION

         1. WIND SPEED
            < 2.5 M/S           1576            37325              -35749              .004
            2.5 TO 5. M/S       1813            32874              -31060              .028
            > 5. M/S             551            15344              -14792              .001
--------------------------------------------------------------------------------------------

         2. STABILITY GROUP
            CLASS A, B & C      1092              276                 816            29.256
            CLASS D             1517               10                1508          3750.474
            CLASS E             1118            21707              -20588              .020
            CLASS F             1667            38639              -36970              .007
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEX/PFM
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	1969	15163	-13193 (-15397,-10989)	.003 (.001, .007)
STATION 1	1316	10509	-9192	.005
STATION 2	318	318	0	.169
STATION 3	1111	4937	-3826	.004
STATION 4	1072	5136	-4062	.003
STATION 5	1374	4229	-2854	.007
STATION 6	1411	9867	-8455	.030
STATION 7	1347	3885	-2538	.007
STATION 8	1103	1510	-407	.048
STATION 9	1183	2285	-1100	.028
STATION 10	339	769	-429	.107
STATION 11	315	421	-105	.191
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	1576	14290	-12713	.003
2.5 TO 5. M/S	1813	10258	-8444	.060
> 5. M/S	551	2643	-2091	.002
2. STABILITY GROUP				
CLASS A, B & C	1092	2547	-1454	.194
CLASS D	1517	7205	-5688	.033
CLASS E	1118	9219	-8101	.027
CLASS F	1667	12700	-11032	.019

145<

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                        SO2 CONCENTRATION VALUES (UG/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                              FOR VARIOUS DATA SETS
                                  MODEL: 4141
                        FOR THE  1-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)

------------------------------------------------------------------------------------------------

       DATA SETS              AVERAGE          AVERAGE          DIFFERENCE        VARIANCE
                              OBSERVED         PREDICTED        OF AVERAGES*      COMPARISON
                              VALUE            VALUE            (OBS-PRED)        (OBS/PRED)

------------------------------------------------------------------------------------------------

       ALL                    1969             12205            -10236              .009
                                                           (-11549, -8922)   ( .004, .020)

       STATION  1             1316              5073             -3757              .111
       STATION  2              318                33               285            44.168
       STATION  3             1110               189               921            45.264
       STATION  4             1072              3205             -2132              .199
       STATION  5             1374              6968             -5593              .012
       STATION  6             1411              2241              -829             1.529
       STATION  7             1347              6821             -5473              .006
       STATION  8             1103              2073              -970              .018
       STATION  9             1183              7499             -6314              .004
       STATION 10              339                70               269            42.523
       STATION 11              315               104               211             5.478

------------------------------------------------------------------------------------------------

       METEOROLOGICAL CONDITION

       1. WIND SPEED
          < 2.5 M/S           1576              8220             -6643              .005
          2.5 TO 5. M/S       1813              9331             -7517              .012
          > 5. M/S             551              1925             -1373              .006

------------------------------------------------------------------------------------------------

       2. STABILITY GROUP
          CLASS A, B & C      1092               204               888            56.170
          CLASS D             1517                 2              1516         85195.351
          CLASS E             1118              3299             -2181              .058
          CLASS F             1667             12205            -10537              .019
```

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                       SO2 CONCENTRATION VALUES (UG/M**3)
                         (UNPAIRED IN TIME OR LOCATION)
                             FOR VARIOUS DATA SETS
                                 MODEL: PLUME5
                       FOR THE  1-HOUR AVERAGING PERIOD
                             WESTVACO (1980/1981)
------------------------------------------------------------------------------------------
        DATA SETS            AVERAGE         AVERAGE          DIFFERENCE        VARIANCE
                             OBSERVED        PREDICTED      OF AVERAGES*       COMPARISON
                              VALUE           VALUE          (OBS-PRED)        (OBS/PRED)
------------------------------------------------------------------------------------------

        ALL                   1969            14525            -12556              .008
                                                         (-13923,-11188)     ( .004, .019)

        STATION  1            1316             9696             -8379              .008
        STATION  2             318               80               238             5.903
        STATION  3            1119             1887              -776              .008
        STATION  4            1072             2154             -1080              .019
        STATION  5            1374             2787             -1412              .016
        STATION  6            1411            12232            -10820              .025
        STATION  7            1347             2831             -1482              .004
        STATION  8            1103              880               223              .122
        STATION  9            1183             1232               -48              .025
        STATION 10             339              327                12              .516
        STATION 11             315               59               256            21.932
------------------------------------------------------------------------------------------

        METEOROLOGICAL CONDITION

        1. WIND SPEED
           < 2.5 M/S          1576             9831             -8254              .005
           2.5 TO 5. M/S      1813            11407             -9593              .012
           > 5. M/S            551            10317             -9765              .001
------------------------------------------------------------------------------------------

        2. STABILITY GROUP
             CLASS A, B & C   1092             4346             -3252              .003
             CLASS D          1517            13745            -12227              .042
             CLASS E          1118             4555             -3436              .013
             CLASS F          1667             2520              -852              .018
```

147<

```
                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                       SO2 CONCENTRATION VALUES (UG/M**3)
                        (UNPAIRED IN TIME OR LOCATION)
                             FOR VARIOUS DATA SETS
                                  MODEL: RTDM
                       FOR THE  1-HOUR AVERAGING PERIOD
                             WESTVACO (1980/1981)

----------------------------------------------------------------------------------------

       DATA SETS          AVERAGE        AVERAGE        DIFFERENCE        VARIANCE
                          OBSERVED       PREDICTED      OF AVERAGES*      COMPARISON
                          VALUE          VALUE          (OBS-PRED)        (OBS/PRED)

----------------------------------------------------------------------------------------

       ALL                  1935           3954            -2018             .722
                                                     ( -2212, -1823)   ( .318,1.638)

       STATION  1           1269           2780            -1510             .172
       STATION  2            269            284              -15           84.369
       STATION  3           1000           1985             -985             .516
       STATION  4            976           2245            -1268             .871
       STATION  5           1284           3035            -1751             .262
       STATION  6           1333           2554            -1219             .309
       STATION  7           1316           3741            -2424             .000
       STATION  8           1909           1990              -80            4.593
       STATION  9           1113           1919             -805             .000
       STATION 10            275            315              -40            9.551
       STATION 11            306            219               88           30.855

----------------------------------------------------------------------------------------

       METEOROLOGICAL CONDITION

       1. WIND SPEED
          < 2.5 M/S         1450           3944            -2492            1.030
          2.5 TO 5. M/S     1787           3774            -1985           10.163
          > 5. M/S           534           1460             -926             .021

----------------------------------------------------------------------------------------

       2. STABILITY GROUP
          CLASS A, B & C     899           3741            -2841             .000
          CLASS D           1456           3742            -2284             .689
          CLASS E           1005           2688            -1683             .200
          CLASS F           1596           3742            -2145            8.697
```

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                            (UNPAIRED IN TIME OR LOCATION)
                                FOR VARIOUS DATA SETS
                                    MODEL: SHORTZ
                           FOR THE  1-HOUR AVERAGING PERIOD
                                WESTVACO (1980/1981)

------------------------------------------------------------------------------------------

      DATA SETS             AVERAGE         AVERAGE        DIFFERENCE         VARIANCE
                            OBSERVED        PREDICTED      OF AVERAGES*       COMPARISON
                             VALUE           VALUE          (OBS-PRED)        (OBS/PRED)

------------------------------------------------------------------------------------------

      ALL                     1969           13563           -11594              .007
                                                       (-13075,-10112)     ( .003, .016)

      STATION  1              1316           10032           -8715               .012
      STATION  2               318             380             -61              4.756
      STATION  3              1110            6491           -5380               .006
      STATION  4              1072            5641           -4568               .031
      STATION  5              1374            2700           -1325               .303
      STATION  6              1411           10851           -9439               .012
      STATION  7              1347            2942           -1594               .137
      STATION  8              1103            1254            -150               .379
      STATION  9              1183            1490            -306               .263
      STATION 10               339             410             -70              1.077
      STATION 11               315             215             100              2.227

------------------------------------------------------------------------------------------

      METEOROLOGICAL CONDITION

      1. WIND SPEED
         < 2.5 M/S            1576            8401           -6823               .013
         2.5 TO 5. M/S        1813           13060          -11246               .010
         > 5. M/S              551            2458           -1906               .001

------------------------------------------------------------------------------------------

      2. STABILITY GROUP
         CLASS A, B & C       1092            3678           -2585               .017
         CLASS D              1517            7912           -6394               .022
         CLASS E              1118            6513           -5395               .026
         CLASS F              1667           12362          -10695               .029
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	1127	12205	-11076 (-11845,-10311)	-10433 (-11000,-10157)	.026 (.011, .058)	1.00 (.385)
COMPLEXII	1127	20557	-19436 (-20871,-17988)	-17793 (-21880,-17031)	.007 (.003, .015)	1.00 (.385)
4141	1127	4769	-3642 (-4283, -3000)	-3552 (-4107, -2712)	.037 (.016, .084)	1.00 (.385)
RTDM	1127	1464	-337 (-545, -127)	-256 (-502, -135)	.473 (.209,1.075)	.52 (.385)
PLUMES	1127	7817	-6690 (-8051, -5329)	-5534 (-6958, -4625)	.008 (.004, .018)	1.00 (.385)
COMPLEX/PFM	1127	7729	-6601 (-7549, -5652)	-6053 (-6977, -5255)	.017 (.007, .038)	1.00 (.385)
SHORTZ	1127	5330	-5202 (-5780, -4624)	-5043 (-5370, -4323)	.046 (.020, .104)	1.00 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

```
                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                      SO2 CONCENTRATION VALUES (UG/M**3)
                        (UNPAIRED IN TIME OR LOCATION)
                            FOR VARIOUS DATA SETS
                              MODEL: COMPLEX I
                       FOR THE 3-HOUR AVERAGING PERIOD
                            WESTVACO (1980/1981)
---------------------------------------------------------------------------------------------
     DATA SETS          AVERAGE         AVERAGE         DIFFERENCE          VARIANCE
                        OBSERVED       PREDICTED       OF AVERAGES,        COMPARISON
                         VALUE           VALUE          (OBS-PRED)          (OBS/PRED)
---------------------------------------------------------------------------------------------

     ALL                  1127           12205            -11078               .026
                                                     (-11845,-10311)       ( .011, .058)

     STATION  1            759           10432             -9672               .010
     STATION  2            165               9               156              7.322
     STATION  3            616            7685             -7069               .008
     STATION  4            615            6134             -5519               .008
     STATION  5            717            3489             -2772               .039
     STATION  6            790            9951             -9161               .044
     STATION  7            718            2800             -2082               .018
     STATION  8            526             854              -327               .032
     STATION  9            578            1354              -776               .047
     STATION 10            204             345              -141              2.508
     STATION 11            200              73               127              1.713
```

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                         SO2 CONCENTRATION VALUES (UG/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                               FOR VARIOUS DATA SETS
                                 MODEL: COMPLEXII
                          FOR THE  3-HOUR AVERAGING PERIOD
                                WESTVACO (1980/1981)

------------------------------------------------------------------------------------------

   DATA SETS            AVERAGE         AVERAGE          DIFFERENCE          VARIANCE
                        OBSERVED        PREDICTED        OF AVERAGES*        COMPARISON
                        VALUE           VALUE            (OBS-PRED)          (OBS/PRED)

------------------------------------------------------------------------------------------

   ALL                    1127            20557            -19430               .007
                                                     (-20871,-17988)     ( .003, .016)

   STATION  1              759            16699            -15939               .004
   STATION  2              165               10               155             20.051
   STATION  3              618             9889             -9270               .002
   STATION  4              615             7453             -6837               .002
   STATION  5              717             3541             -2823               .007
   STATION  6              788            17242            -16453               .005
   STATION  7              718             3164             -2444               .007
   STATION  8              526              787              -259               .012
   STATION  9              578             1571              -992               .017
   STATION 10              204              677              -472               .119
   STATION 11              200               63               137              5.019
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEX/PFM
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	1127	7728	-6601 (-7549, -5652)	.017 (.007, .038)
STATION 1	759	4137	-3376	.008
STATION 2	165	105	58	.128
STATION 3	619	1776	-1157	.007
STATION 4	615	1808	-1192	.005
STATION 5	717	1557	-840	.023
STATION 6	788	5516	-4727	.026
STATION 7	718	1285	-567	.042
STATION 8	526	497	30	.095
STATION 9	578	779	-200	.117
STATION 10	204	340	-135	.377
STATION 11	200	193	7	.540

```
                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                    SO2 CONCENTRATION VALUES (UG/M**3)
                      (UNPAIRED IN TIME OR LOCATION)
                         FOR VARIOUS DATA SETS
                              MODEL: 4141
                    FOR THE  3-HOUR AVERAGING PERIOD
                         WESTVACO (1980/1981)

-------------------------------------------------------------------------------------------
        DATA SETS           AVERAGE          AVERAGE          DIFFERENCE          VARIANCE
                            OBSERVED        PREDICTED        OF AVERAGES*        COMPARISON
                             VALUE            VALUE           (OBS-PRED)          (OBS/PRED)
-------------------------------------------------------------------------------------------

        ALL                  1127             4769             -3642                .037
                                                         ( -4283, -3000)      ( .016, .084)

        STATION  1            759             2240             -1480                .088
        STATION  2            165               10               155              22.623
        STATION  3            618               84               534              82.409
        STATION  4            615             1160              -544                .134
        STATION  5            717             2465             -1748                .029
        STATION  6            788             1246              -457                .515
        STATION  7            718             2001             -1281                .023
        STATION  8            526              582               -54                .027
        STATION  9            578             2200             -1622                .011
        STATION 10            204               31               173              23.916
        STATION 11            200               50               150              12.871
```

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                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                        SO2 CONCENTRATION VALUES (UG/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                              FOR VARIOUS DATA SETS
                                  MODEL: PLUMES
                       FOR THE  3-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)
------------------------------------------------------------------------------------------
       DATA SETS          AVERAGE         AVERAGE         DIFFERENCE        VARIANCE
                          OBSERVED        PREDICTED       OF AVERAGES*      COMPARISON
                           VALUE           VALUE          (OBS-PRED)        (OBS/PRED)
------------------------------------------------------------------------------------------

       ALL                 1127            7817             -6690             .008
                                                      ( -8051, -5329)   ( .004, .019)

       STATION  1           761            3852             -3090             .007
       STATION  2           165              25               139            2.134
       STATION  3           618             885              -265             .021
       STATION  4           615             645               -30             .064
       STATION  5           717            1283              -567             .012
       STATION  6           788            5739             -4951             .010
       STATION  7           718             930              -210             .027
       STATION  8           526             289               237             .252
       STATION  9           578             427               151             .115
       STATION 10           204             125                78            1.899
       STATION 11           200              28               172           25.630
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: RTDM
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	1088	3580	-2492 (-2700, -2283)	.531 (.234,1.206)
STATION 1	708	1666	-957	.151
STATION 2	131	225	-93	2.760
STATION 3	538	1287	-748	.312
STATION 4	506	1513	-1006	.203
STATION 5	676	1638	-961	.085
STATION 6	722	1314	-593	.395
STATION 7	681	2964	-2283	.083
STATION 8	476	951	-473	5.187
STATION 9	536	1539	-1001	.267
STATION 10	162	228	-66	1.515
STATION 11	184	189	-4	3.597

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```
                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                       SO2 CONCENTRATION VALUES (UG/M**3)
                        (UNPAIRED IN TIME OR LOCATION)
                            FOR VARIOUS DATA SETS
                               MODEL: SHORTZ
                       FOR THE  3-HOUR AVERAGING PERIOD
                             WESTVACO (1980/1981)

----------------------------------------------------------------------------------------------------

      DATA SETS            AVERAGE            AVERAGE          DIFFERENCE          VARIANCE
                           OBSERVED          PREDICTED       OF AVERAGES*         COMPARISON
                            VALUE              VALUE           (OBS-PRED)          (OBS/PRED)

----------------------------------------------------------------------------------------------------

      ALL                   1127               6330             -5202                .046
                                                         ( -5780, -4624)      ( .020, .104)

      STATION  1             761               4510             -3748                .041
      STATION  2             165                171                -5               1.739
      STATION  3             618               3079             -2459                .010
      STATION  4             615               2585             -1969                .024
      STATION  5             717               1129              -411                .924
      STATION  6             788               5019             -4230                .043
      STATION  7             718               1290              -570                .310
      STATION  8             526                539               -12                .395
      STATION  9             578                647               -69                .549
      STATION 10             204                252               -47                .570
      STATION 11             200                112                88               4.744
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	354	3238	-2883 (-3141, -2624)	-2728 (-2886, -2574)	.007 (.003, .017)	1.00 (.385)
COMPLEXII	354	4482	-4127 (-4667, -3597)	-3504 (-4221, -3306)	.002 (.001, .004)	1.00 (.385)
4141	354	855	-500 (-644, -357)	-382 (-443, -317)	.024 (.011, .055)	1.00 (.385)
RTDM	354	331	23 (-37, 83)	57 (32, 92)	.143 (.063, .324)	.55 (.385)
PLUMES	354	1712	-1357 (-2040, -674)	-730 (-892, -559)	.001 (.000, .002)	1.00 (.385)
COMPLEX/PFM	354	1584	-1229 (-1480, -978)	-1201 (-1393, -887)	.008 (.005, .019)	1.00 (.385)
SHORTZ	354	1388	-1033 (-1175, -891)	-944 (-1150, -824)	.025 (.011, .057)	1.00 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                     SO2 CONCENTRATION VALUES (UG/M**3)
                       (UNPAIRED IN TIME OR LOCATION)
                           FOR VARIOUS DATA SETS
                             MODEL: COMPLEXI
                      FOR THE 24-HOUR AVERAGING PERIOD
                           WESTVACO (1981/1981)
--------------------------------------------------------------------------------------------------
      DATA SETS          AVERAGE          AVERAGE          DIFFERENCE           VARIANCE
                         OBSERVED         PREDICTED        OF AVERAGES*        COMPARISON
                          VALUE            VALUE           (OBS-PRED)          (OBS/PRED)
--------------------------------------------------------------------------------------------------

      ALL                  354             3238               -2883                .007
                                                         ( -3141, -2624)     ( .003, .017)

      STATION  1           201             2356               -2155                .010
      STATION  2            63                2                  61              22.734
      STATION  3           172             1486               -1314                .028
      STATION  4           156             1033                -876                .021
      STATION  5           169              591                -422                .024
      STATION  6           262             2824               -2541                .012
      STATION  7           152              435                -282                .009
      STATION  8           137              122                  15                .087
      STATION  9           138              204                 -65                .059
      STATION 10            66               76                  -9                .649
      STATION 11            67               13                  55               5.566
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                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                           (UNPAIRED IN TIME OR LOCATION)
                               FOR VARIOUS DATA SETS
                                  MODEL: COMPLEXII
                         FOR THE 24-HOUR AVERAGING PERIOD
                                WESTVACO (1980/1981)
------------------------------------------------------------------------------------------------
     DATA SETS            AVERAGE           AVERAGE          DIFFERENCE         VARIANCE
                          OBSERVED          PREDICTED        OF AVERAGES*       COMPARISON
                           VALUE             VALUE           (OBS-PRED)         (OBS/PRED)
------------------------------------------------------------------------------------------------
                                                              -4127               .002
     ALL                   354               4482        ( -4667, -3587)     ( .001, .004)

     STATION  1            201               3058             -2856               .003
     STATION  2             63                  2                61             51.305
     STATION  3            172               1655             -1481               .011
     STATION  4            156               1114              -956               .008
     STATION  5            169                502              -332               .013
     STATION  6            282               3810             -3527               .004
     STATION  7            152                489              -336               .004
     STATION  8            137                111                26               .036
     STATION  9            139                234               -95               .024
     STATION 10             65                109               -42               .121
     STATION 11             67                 12                56             14.680
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEX/PFM
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	354	1584	-1229 (-1480, -978)	.008 (.003, .018)
STATION 1	201	710	-507	.024
STATION 2	63	14	49	.333
STATION 3	172	267	-94	.044
STATION 4	156	237	-80	.023
STATION 5	169	209	-39	.078
STATION 6	282	1046	-763	.006
STATION 7	152	152	0	.050
STATION 8	137	71	66	.321
STATION 9	138	108	30	.279
STATION 10	65	55	11	.934
STATION 11	67	37	31	1.289

```
                     COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                            (UNPAIRED IN TIME OR LOCATION)
                                FOR VARIOUS DATA SETS
                                    MODEL: 4141
                          FOR THE 24-HOUR AVERAGING PERIOD
                                WESTVACO (1980/1981)

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          DATA SETS          AVERAGE          AVERAGE          DIFFERENCE          VARIANCE
                             OBSERVED         PREDICTED        OF AVERAGES*        COMPARISON
                              VALUE            VALUE           (OBS-PRED)          (OBS/PRED)

--------------------------------------------------------------------------------------------------

          ALL                  354              855                -500                .024
                                                             ( -644,  -357)      ( .011, .055)

          STATION  1           201              410                -208                .214
          STATION  2            63                2                  62              43.534
          STATION  3           172               16                 156             188.667
          STATION  4           156              174                 -16                .314
          STATION  5           169              374                -204                .040
          STATION  6           282              286                  -3                .215
          STATION  7           152              295                -143                .014
          STATION  8           137               94                  43                .055
          STATION  9           138              343                -205                .015
          STATION 10            66                7                  59              38.465
          STATION 11            67                9                  58              59.597
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                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                         SO2 CONCENTRATION VALUES (UG/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                               FOR VARIOUS DATA SETS
                                  MODEL: PLUMES
                          FOR THE 24-HOUR AVERAGING PERIOD
                               WESTVACO (1980/1981)
---------------------------------------------------------------------------------------------------
      DATA SETS           AVERAGE          AVERAGE          DIFFERENCE          VARIANCE
                          OBSERVED         PREDICTED        OF AVERAGES*        COMPARISON
                           VALUE            VALUE           (OBS-PRED)          (OBS/PRED)
---------------------------------------------------------------------------------------------------
      ALL                   354             1712              -1357               .001
                                                          ( -2040,   -674)     ( .000, .002)

      STATION  1            201              719               -516               .017
      STATION  2             63                5                 59              4.006
      STATION  3            172              193                -20               .095
      STATION  4            156              128                 29               .159
      STATION  5            169              184                -15               .037
      STATION  6            282             1290              -1008               .001
      STATION  7            152              127                 25               .028
      STATION  8            137               40                 97               .911
      STATION  9            138               61                 77               .311
      STATION 10             65               23                 41              1.605
      STATION 11             67                5                 62            102.463
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COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: RTDM
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES, (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	346	2080	-1733 (-2111, -1355)	.004 (.002, .010)
STATION 1	192	695	-501	.048
STATION 2	57	115	-58	.055
STATION 3	161	639	-477	.049
STATION 4	141	883	-742	.039
STATION 5	163	633	-469	.016
STATION 6	272	405	-133	.082
STATION 7	147	1296	-1149	.061
STATION 8	124	665	-540	.142
STATION 9	129	714	-584	.011
STATION 10	57	107	-48	.165
STATION 11	63	99	-35	.155

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                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                      SO2 CONCENTRATION VALUES (UG/M**3)
                        (UNPAIRED IN TIME OR LOCATION)
                            FOR VARIOUS DATA SETS
                               MODEL: SHORTZ
                      FOR THE 24-HOUR AVERAGING PERIOD
                            WESTVACO (1980/1981)
-------------------------------------------------------------------------------------------
      DATA SETS           AVERAGE          AVERAGE          DIFFERENCE         VARIANCE
                          OBSERVED         PREDICTED        OF AVERAGES,       COMPARISON
                          VALUE            VALUE            (OBS-PRED)         (OBS/PRED)
-------------------------------------------------------------------------------------------
      ALL                   354              1388             -1033               .025
                                                         ( -1175,  -891)     ( .011, .057)

      STATION  1            201               934              -731               .066
      STATION  2             63                37                27               .511
      STATION  3            179               566              -387               .034
      STATION  4            156               443              -286               .135
      STATION  5            169               225               -55               .621
      STATION  6            289              1196              -907               .840
      STATION  7            152               211               -59               .151
      STATION  8            137                83                54              1.259
      STATION  9            138                99                39              1.147
      STATION 10             67                68                -1               .572
      STATION 11             67                30                37              4.086
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COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	1859	-8939 (-14352, -3526)	.27	8058 (5630,14141)	11788	9149	.79	.74	.007 (.002, .028)
COMPLEXII	11	1859	-23851 (-35674,-12028)	.18	17600 (12297,30986)	29164	24093	.85	.79	.002 (.000, .005)
4141	11	1859	-5513 (-10353, -673)	.36	7204 (5034,12543)	8809	6165	.54	.49	.010 (.003, .036)
RTDM	11	1859	-661 (-1552, 230)	.45	1327 (927, 2328)	1428	1106	.76	.68	.171 (.045, .638)
PLUMES	11	1859	-8679 (-14375, -3384)	.18	8141 (5715,14357)	11820	9123	.76	.76	.007 (.002, .027)
COMPLEX/PFM	11	1859	-12032 (-18747, -5317)	.30	9976 (6985,17547)	15351	12033	.82	.89	.005 (.001, .018)
SHORTZ	11	1859	-6469 (-11809, -1130)	.18	7949 (5554,13750)	9965	6525	.57	.72	.003 (.002, .023)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	1229	-6391 (-10128, -2653)	.27	5563 (3887, 9763)	8306	6482	.72	.56	.009 (.002, .034)
COMPLEXII	11	1229	-11006 (-17281, -4732)	.18	9340 (6525,16391)	14159	11120	.70	.50	.003 (.001, .013)
4141	11	1229	-2495 (-4621, -369)	.36	3165 (2211, 5554)	3915	2896	.70	.74	.025 (.007, .095)
RTDM	11	1229	-64 (-409, 280)	.54	513 (359, 901)	494	401	.81	.73	.445 (.113,1.544)
PLUMES	11	1229	-4664 (-8582, -1147)	.27	5534 (3867, 9712)	7177	5900	.73	.77	.009 (.002, .034)
COMPLEX/PFM	11	1229	-4863 (-7953, -1773)	.00	4600 (3214, 8073)	6549	4864	.60	.53	.013 (.004, .049)
SHORTZ	11	1229	-2736 (-5129, -343)	.18	3562 (2463, 6251)	4362	2801	.45	.45	.022 (.006, .083)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 24 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	317	-1416 (-2425, -407)	.18	1502 (1050, 2636)	2015	1433	.92	.89	.007 (.002, .028)
COMPLEXII	11	317	-2401 (-4152, -650)	.18	2506 (1821, 4574)	3456	2442	.77	.84	.003 (.001, .010)
4141	11	317	-435 (-877, 6)	.36	658 (460, 1154)	764	572	.43	.42	.040 (.011, .147)
PTDM	11	317	7 (-105, 113)	.73	168 (117, 294)	160	139	.74	.72	.330 (.039,1.227)
PLUMES	11	317	-1272 (-2886, 341)	.36	2462 (1679, 4216)	2521	1336	.52	.84	.003 (.001, .012)
COMPLEX/PFM	11	317	-823 (-1481, -165)	.09	973 (664, 1717)	1245	937	.81	.94	.015 (.004, .051)
SHORTZ	11	317	-564 (-995, -133)	.36	731 (511, 1283)	851	555	.76	.83	.023 (.006, .079)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	1617	-8039 (-12784, -3294)	.27	7053 (4935,12395)	10488	8156	.75	.58	.009 (.002, .034)
COMPLEXII	11	1617	-21317 (-31857,-10776)	.18	15691 (10964,27536)	26044	21440	.83	.58	.002 (.001, .007)
4141	11	1617	-4928 (-9125, -731)	.36	6248 (4366,10365)	7732	5430	.64	.59	.012 (.003, .045)
RTDM	11	1617	-450 (-1150, 250)	.55	1043 (729, 1830)	1092	918	.75	.55	.245 (.066, .912)
PLUMES	11	1617	-7082 (-11279, -2885)	.18	6248 (4365,10964)	9255	7191	.79	.70	.012 (.003, .043)
COMPLEX/PFM	11	1617	-8250 (-12262, -4239)	.00	5971 (4172,10479)	10025	8251	.82	.58	.012 (.003, .046)
SHORTZ	11	1617	-5830 (-10667, -993)	.09	7206 (5031,12536)	9007	5864	.54	.55	.009 (.003, .035)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	990	-5756 (-9441, -2071)	.18	5485 (3833, 9626)	7778	5833	.73	.72	.005 (.002, .028)
COMPLEXII	11	990	-9967 (-16045, -3928)	.18	9019 (6301,15827)	13179	10073	.76	.76	.003 (.001, .011)
4141	11	990	-1851 (-3367, -335)	.36	2255 (1577, 3960)	2839	2150	.68	.71	.039 (.011, .146)
RTDM	11	990	47 (-238, 332)	.54	425 (297, 746)	408	346	.92	.87	.435 (.133,1.844)
PLUMES	11	990	-2930 (-5538, -322)	.27	3883 (2713, 6814)	4722	3032	.71	.83	.014 (.004, .054)
COMPLEX/PFM	11	990	-3862 (-6236, -1489)	.09	3533 (2469, 6201)	5126	3954	.67	.57	.017 (.005, .065)
SHORTZ	11	990	-2139 (-3899, -379)	.09	2619 (1830, 4597)	3289	2177	.61	.74	.031 (.008, .114)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 24 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	11	256	-1235 (-2147, -323)	.18	1357 (948, 2382)	1790	1262	.87	.90	.005 (.002, .024)
COMPLEXII	11	256	-1891 (-3337, -446)	.18	2152 (1504, 3777)	2791	1921	.84	.92	.003 (.001, .010)
4141	11	255	-238 (-496, 19)	.36	384 (268, 674)	437	350	.47	.35	.075 (.020, .279)
KTDM	11	255	38 (-19, 95)	.82	87 (61, 152)	91	74	.85	.86	.529 (.142,1.958)
PLUMES	11	256	-635 (-1383, 112)	.36	1114 (778, 1955)	1238	580	.73	.95	.009 (.003, .033)
COMPLEX/PFM	11	256	-578 (-1120, -37)	.27	806 (563, 1415)	963	591	.78	.88	.017 (.005, .053)
SHORTZ	11	256	-366 (-743, 10)	.36	562 (392, 985)	649	403	.92	.91	.032 (.009, .118)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                    COMPARISON OF HIGHEST OBSERVED AND PREDICTED
                       SO2 CONCENTRATION VALUES (UG/M**3)
                        EVENT-BY-EVENT (PAIRED IN TIME)
                        FOR THE  1-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)

------------------------------------------------------------------------------------------------
MODEL              NUMBER        AVERAGE          AVERAGE           STANDARD         MAXIMUM
                     OF          OBSERVED        DIFFERENCE*        DEVIATION*       FREQUENCY
                   EVENTS         VALUE          (OBS-PRED)       OF RESIDUALS      DIFFERENCE
------------------------------------------------------------------------------------------------

COMP_EXI            7173           154              -947              3061              .775
                                            ( -1117,  -778)   (  3012,  3112)   (     .323)

COMP_EXII           7163           155             -1237              5073              .764
                                            ( -1441, -1033)   (  4992,  5158)   (     .323)

4141                7132           155               -36               963              .305
                                            (   -73,     1)   (   947,   979)   (     .323)

RTDM                7411           150                59               332              .315
                                            (    46,    72)   (   326,   337)   (     .322)

PLUMES              7365           152              -153              1354              .435
                                            (  -213,   -94)   (  1333,  1376)   (     .323)

COMP_EX/PFM         7102           155               -66              1369              .417
                                            (  -125,    -6)   (  1347,  1392)   (     .323)

SHORTZ              7785           143              -365              1297              .247
                                            (  -415,  -315)   (  1277,  1317)   (     .322)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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                    COMPARISON OF HIGHEST OBSERVED AND PREDICTED
                         SO2 CONCENTRATION VALUES (UG/M**3)
                           EVENT-BY-EVENT (PAIRED IN TIME)
                           FOR THE  3-HOUR AVERAGING PERIOD
                                WESTVACO (1980/1981)
---------------------------------------------------------------------------------------------
   MODEL           NUMBER        AVERAGE        AVERAGE           STANDARD         MAXIMUM
                     OF          OBSERVED     DIFFERENCE*        DEVIATION*       FREQUENCY
                   EVENTS         VALUE       (OBS-PRED)       OF RESIDUALS      DIFFERENCE
---------------------------------------------------------------------------------------------
   COMPLEXI         2443           139            -838              2362             .573
                                             ( -1005,  -670)    ( 2298,  2433)    (  .039)

   COMPLEXII        2429           140           -1077              3475             .705
                                             ( -1293,  -860)    ( 3380,  3575)    (  .039)

   4141             2415           140             -25               625             .743
                                             (   -68,    17)    (  608,   644)    (  .039)

   RTDM             2514           136              53               236             .154
                                             (    39,    67)    (  229,   242)    (  .039)

   PLUMES           2477           138            -137              1029             .391
                                             (  -215,   -58)    ( 1001,  1059)    (  .039)

   COMPLEX/PFM      2415           140             -56               987             .752
                                             (  -113,     2)    (  960,  1015)    (  .039)

   SHORTZ           2612           131            -335               902             .295
                                             (  -388,  -281)    (  878,   927)    (  .039)

   * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMP_EXI	363	98	-600 (-729, -471)	949 (885, 1023)	.455 (.101)
COMP_EXII	363	98	-755 (-923, -581)	1320 (1231, 1425)	.311 (.101)
4141	363	98	-17 (-52, 19)	225 (209, 242)	.455 (.101)
RTDM	365	98	37 (24, 50)	96 (90, 104)	.537 (.101)
PLUMES	365	98	-99 (-162, -35)	574 (536, 621)	.255 (.101)
COMPLEX/PFM	362	98	-32 (-81, 17)	393 (367, 425)	.519 (.101)
SHORTZ	365	98	-255 (-300, -210)	359 (335, 387)	.479 (.101)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                         COMPARISON OF ALL OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                              PAIRED IN TIME AND LOCATION
                             FOR THE  1-HOUR AVERAGING PERIOD
                                SUMMARY TABLE (PART 1)
                                 WESTVACO (1980/1981)
-----------------------------------------------------------------------------------------------------------------
     MODEL           NUMBER         AVERAGE          AVERAGE            STANDARD          MAXIMUM
                       OF          OBSERVED        DIFFERENCE*         DEVIATION*        FREQUENCY
                     EVENTS          VALUE         (OBS-PRED)        OF RESIDUALS       DIFFERENCE
-----------------------------------------------------------------------------------------------------------------

     COMPLEXI        30704            95              -227               1709             ******
                                                 ( -262,  -192)     ( 1696,  1723)      (  .011)

     COMPLEXII       30682            93              -241               2535             ******
                                                 ( -282,  -200)     ( 2515,  2555)      (  .011)

     4141            30656            95                42                535             ******
                                                 (   35,    50)     (  531,   545)      (  .011)

     RTDM            32336            90                55                212             ******
                                                 (   51,    59)     (  210,   214)      (  .011)

     PLUMES          31595            93                14                676             ******
                                                 (    1,    26)     (  671,   681)      (  .011)

     COMPLEX/PFM     30463            95                31                733             ******
                                                 (   20,    43)     (  727,   739)      (  .011)

     SHORTZ          34879            84               -82                691             ******
                                                 (  -93,   -71)     (  686,   595)      (  .010)

     * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.95	1724	406	.008	.115	.008 (.007, .009)
COMPLEXII	.95	2547	421	.015	.115	.004 (.003, .004)
4141	.95	537	138	.059	.295	.085 (.077, .093)
RTDM	.87	219	102	.079	-.004	.844 (.757, .928)
PLUME5	.87	576	145	.051	.269	.051 (.047, .056)
COMPLEX/PFM	.96	783	151	.109	.151	.045 (.041, .050)
SHORTZ	.70	596	216	.046	-.138	.045 (.041, .050)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEX I
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	30704	95	-227	1703
STATION 1	3722	112	-589	2610
STATION 2	2247	52	51	44
STATION 3	3155	94	-302	1983
STATION 4	2423	104	-209	1742
STATION 5	2568	97	-46	998
STATION 6	3864	161	-958	3012
STATION 7	2344	106	-6	989
STATION 8	2840	76	53	383
STATION 9	2411	85	32	495
STATION 10	2364	57	16	128
STATION 11	2766	56	53	45
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	8026	130	-168	44
2.5 TO 5. M/S	15227	89	-359	44
> 5. M/S	7451	70	-20	25
2. STABILITY GROUP				
CLASS A, B & C	5867	94	86	11
CLASS D	14821	84	84	11
CLASS E	3431	86	-830	49
CLASS F	6585	125	-890	56

177<

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                         COMPARISON OF ALL OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                              PAIRED IN TIME AND LOCATION
                                (FOR VARIOUS DATA SETS)
                                   MODEL: COMPLEXII
                             FOR THE  1-HOUR AVERAGING PERIOD
                                 WESTVACO (1980/1981)

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        DATA SET              NUMBER          AVERAGE          AVERAGE          STANDARD
                                OF            OBSERVED        DIFFERENCE        DEVIATION
                              EVENTS           VALUE          (OBS-PRED)      OF RESIDUALS

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        ALL                   30682               95             -241             2535

        STATION  1             3731              112             -652             4572
        STATION  2             2240               52               51               44
        STATION  3             3166               94             -273             2680
        STATION  4             2424              104             -213             2609
        STATION  5             2567               97              -18             1369
        STATION  6             3688              160            -1029             4477
        STATION  7             2546              106              -23             1642
        STATION  8             2838               78               56              619
        STATION  9             2414               85               27              804
        STATION 10             2289               54               13              239
        STATION 11             2779               56               53               45

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        METEOROLOGICAL CONDITION

        1. WIND SPEED
            < 2.5 M/S          8026              130             -187               53
            2.5 TO 5. M/S     15198               88             -371               59
            > 5. M/S           7458               70              -34               33

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        2. STABILITY GROUP
            CLASS A, B & C     5901               97               86               11
            CLASS D           14823               86               84               11
            CLASS E            3453               85             -859               58
            CLASS F            6505              125             -959               69
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                     COMPARISON OF ALL OBSERVED AND PREDICTED
                      SO2 CONCENTRATION VALUES (UG/M**3)
                           PAIRED IN TIME AND LOCATION
                            (FOR VARIOUS DATA SETS)
                              MODEL: COMPLEX/PFM
                      FOR THE  1-HOUR AVERAGING PERIOD
                             WESTVACO (1980/1981)
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        DATA SET              NUMBER           AVERAGE          AVERAGE          STANDARD
                                OF             OBSERVED         DIFFERENCE       DEVIATION
                              EVENTS            VALUE           (OBS-PRED)      OF RESIDUALS
---------------------------------------------------------------------------------------------------------

        ALL                   30465              98               31               733

        STATION  1             4490             113              -13              1054
        STATION  2             2242              52               48                76
        STATION  3             3109              98               42               674
        STATION  4             2413             104               31              1007
        STATION  5             2578              97               48               703
        STATION  6             3752             165              -24              1217
        STATION  7             2346             105               61               654
        STATION  8             2036              70               63               249
        STATION  9             2418              82               58               347
        STATION 10             2264              55               33               116
        STATION 11             2817              55               44                67

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        METEOROLOGICAL CONDITION

        1. WIND SPEED
            < 2.5 M/S           8108             128               27                31
            2.5 TO 5. M/S      14908              91               21                27
            > 5. M/S            7449              78               57                16

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        2. STABILITY GROUP
            CLASS A, B & C      6070              91               33                16
            CLASS D            14895              87               65                22
            CLASS E             3273              95              -53                32
            CLASS F             6227             131               -8                35
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: 4141
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	30658	95	42	535
STATION 1	3758	111	-4	594
STATION 2	2238	52	51	44
STATION 3	3143	95	91	149
STATION 4	2435	103	52	401
STATION 5	2573	97	12	838
STATION 6	3902	160	68	370
STATION 7	2343	106	27	886
STATION 8	2840	78	60	416
STATION 9	2414	85	0	974
STATION 10	2228	56	54	51
STATION 11	2784	56	53	45
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	7997	130	78	26
2.5 TO 5. M/S	15183	85	18	24
> 5. M/S	7478	70	54	13
2. STABILITY GROUP				
CLASS A, B & C	5933	92	87	11
CLASS D	14621	84	84	11
CLASS E	3448	85	-14	21
CLASS F	6456	127	-63	33

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: PLUMES
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	31505	93	14	676
STATION 1	3970	106	-56	1004
STATION 2	2245	52	50	43
STATION 3	3241	92	49	417
STATION 4	2491	101	66	398
STATION 5	2593	97	53	622
STATION 6	4231	148	-156	1262
STATION 7	2367	105	72	698
STATION 8	2653	78	70	227
STATION 9	2429	86	69	295
STATION 10	2320	54	43	69
STATION 11	2765	56	55	44
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	8247	127	61	27
2.5 TO 5. M/S	15623	87	18	25
> 5. M/S	7635	68	-46	27
2. STABILITY GROUP				
CLASS A, B & C	6091	91	38	22
CLASS D	15470	81	-37	29
CLASS E	3421	86	31	23
CLASS F	6488	127	103	18

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: RTDM
FOR THE 1-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	38228	66	-82	394
STATION 1	4303	83	-80	408
STATION 2	2452	40	2	85
STATION 3	3535	70	-86	350
STATION 4	3271	64	-165	452
STATION 5	3179	67	-108	489
STATION 6	4572	122	-16	333
STATION 7	3599	61	-211	706
STATION 8	3831	52	-100	282
STATION 9	3514	52	-116	388
STATION 10	2753	37	-4	82
STATION 11	3219	42	11	68
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	8732	84	-104	22
2.5 TO 5. M/S	20290	62	-88	20
> 5. M/S	9206	58	-48	16
2. STABILITY GROUP				
CLASS A, B & C	7743	52	-125	21
CLASS D	16685	62	-52	18
CLASS E	8229	62	-65	19
CLASS F	[illegible]	87	-106	22

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                    COMPARISON OF ALL OBSERVED AND PREDICTED
                     SO2 CONCENTRATION VALUES (UG/M**3)
                         PAIRED IN TIME AND LOCATION
                          (FOR VARIOUS DATA SETS)
                              MODEL: SHORTZ
                     FOR THE 1-HOUR AVERAGING PERIOD
                           WESTVACO (1980/1981)
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      DATA SET               NUMBER          AVERAGE          AVERAGE          STANDARD
                               OF            OBSERVED        DIFFERENCE        DEVIATION
                             EVENTS           VALUE          (OBS-PRED)      OF RESIDUALS
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      ALL                    34879              84              -82              691

      STATION  1              4580              93             -235              998
      STATION  2              2403              45               34               71
      STATION  3              3698              82              -94              795
      STATION  4              2944              87              -78              690
      STATION  5              2766              91               22              352
      STATION  6              4918             128             -385             1157
      STATION  7              2455             102               34              395
      STATION  8              2900              77               57              191
      STATION  9              2490              83               52              223
      STATION 10              2700              47               12               91
      STATION 11              3025              52               39               58
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      METEOROLOGICAL CONDITION

      1. WIND SPEED
           < 2.5 M/S          9326             113              -63               26
           2.5 TO 5. M/S     17139              85             -115               23
           > 5. M/S           8414              67              -37               17
--------------------------------------------------------------------------------------------

      2. STABILITY GROUP
           CLASS A, B & C     4562              85                8               18
           CLASS D           17215              77              -66               22
           CLASS E            7841              78             -126               27
           CLASS F            7197             115             -175               34
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 3-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	10600	89	-222 (-262, -181)	1322 (1304, 1340)	.391 (.019)
COMPLEXII	10556	89	-237 (-285, -188)	1806 (1782, 1831)	.385 (.019)
4141	10510	89	38 (29, 47)	359 (354, 364)	.393 (.019)
RTDM	11134	89	51 (47, 55)	160 (157, 162)	.595 (.018)
PLUMES	10825	87	11 (-5, 27)	524 (517, 531)	.745 (.018)
COMPLEX/PFM	10487	89	27 (19, 41)	536 (529, 543)	.399 (.019)
SHORTZ	12096	79	-81 (-94, -67)	507 (501, 514)	.555 (.017)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 3-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.91	1340	392	.010	.102	.008 (.008, .009)
COMPLEXII	.92	1821	399	.019	.100	.005 (.004, .005)
4141	.94	361	125	.064	.097	.123 (.112, .135)
RTDM	.86	157	90	.108	.030	.997 (.907, 1.037)
PLUMES	.85	524	132	.079	.081	.054 (.049, .059)
COMPLEX/PFM	.94	537	140	.003	.134	.054 (.049, .059)
SHORTZ	.65	514	196	.172	-.091	.054 (.049, .059)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEXI
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	10600	88	-222	1322
STATION 1	1539	102	-547	1978
STATION 2	737	56	49	33
STATION 3	1112	87	-288	1459
STATION 4	852	94	-202	1283
STATION 5	869	91	-50	747
STATION 6	1420	144	-870	2281
STATION 7	794	90	-11	698
STATION 8	937	75	50	277
STATION 9	821	78	29	341
STATION 10	818	47	12	131
STATION 11	903	54	51	37

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEXII
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	10556	89	-237	1806
STATION 1	1335	102	-609	2825
STATION 2	739	50	49	39
STATION 3	1113	87	-261	1794
STATION 4	850	94	-207	1674
STATION 5	859	91	-22	695
STATION 6	1420	144	-941	3221
STATION 7	795	99	-28	987
STATION 8	938	75	53	382
STATION 9	623	79	22	477
STATION 10	769	50	9	159
STATION 11	905	54	51	37

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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEX/PFM
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	10487	89	27	536
STATION 1	1519	103	-14	764
STATION 2	743	49	46	47
STATION 3	1085	89	38	510
STATION 4	847	95	26	705
STATION 5	672	91	44	451
STATION 6	1378	148	-25	914
STATION 7	797	96	55	391
STATION 8	941	75	61	183
STATION 9	631	79	52	215
STATION 10	749	51	39	83
STATION 11	925	53	42	52

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: 4141
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	10510	89	38	359
STATION 1	1346	102	-6	423
STATION 2	739	56	49	39
STATION 3	1094	88	85	117
STATION 4	855	94	45	279
STATION 5	879	91	5	555
STATION 6	1425	144	63	285
STATION 7	794	99	21	560
STATION 8	939	76	56	282
STATION 9	822	79	-4	615
STATION 10	719	53	51	42
STATION 11	907	54	51	37

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                        COMPARISON OF ALL OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                              PAIRED IN TIME AND LOCATION
                                (FOR VARIOUS DATA SETS)
                                     MODEL: PLUMES
                          FOR THE  3-HOUR AVERAGING PERIOD
                                 WESTVACO (1980/1981)
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      DATA SET           NUMBER          AVERAGE          AVERAGE          STANDARD
                           OF            OBSERVED        DIFFERENCE        DEVIATION
                         EVENTS           VALUE          (OBS-PRED)      OF RESIDUALS
-------------------------------------------------------------------------------------------

      ALL                10825              87               11               524

      STATION  1          1415              98              -62               746

      STATION  2           739              57               48                38

      STATION  3          1132              86               45               390

      STATION  4           869              97               60               252

      STATION  5           881              91               48               549

      STATION  6          1526             135             -146               996

      STATION  7           805              90               66               415

      STATION  8           948              78               55               139

      STATION  9           835              78               63               186

      STATION 13           778              40               39                51

      STATION 11           497              54               53                36
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                     COMPARISON OF ALL OBSERVED AND PREDICTED
                      SO2 CONCENTRATION VALUES (UG/M**3)
                          PAIRED IN TIME AND LOCATION
                            (FOR VARIOUS DATA SETS)
                                  MODEL: RTDM
                       FOR THE  3-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)
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        DATA SET             NUMBER          AVERAGE          AVERAGE           STANDARD
                               OF            OBSERVED        DIFFERENCE         DEVIATION
                             EVENTS           VALUE          (OBS-PRED)       OF RESIDUALS
------------------------------------------------------------------------------------------------------
        ALL                   11360            62               -85               375
        STATION  1             1342            76               -78               359
        STATION  2              716            38                 0                77
        STATION  3             1068            65               -86               320
        STATION  4              980            58              -166               420
        STATION  5              923            65              -118               493
        STATION  6             1403           113               -17               268
        STATION  7             1049            58              -223               707
        STATION  8             1140            49              -102               267
        STATION  9             1026            50              -120               379
        STATION 10              772            35                -5                75
        STATION 11              941            40                 8                64
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: SHORTZ
FOR THE 3-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	12096	79	-81	507
STATION 1	1658	85	-216	694
STATION 2	820	45	32	51
STATION 3	1305	76	-90	576
STATION 4	1058	78	-73	505
STATION 5	945	85	19	245
STATION 6	1748	119	-360	824
STATION 7	842	94	29	287
STATION 8	958	74	54	140
STATION 9	857	76	47	163
STATION 10	917	43	10	75
STATION 11	388	50	38	47

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 24-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)

MODE_	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	3463	39	-75 (-95, -56)	411 (401, 421)	.341 (.033)
COMPLEXII	3463	39	-81 (-103, -58)	525 (513, 537)	.351 (.033)
4141	3463	39	20 (16, 24)	98 (95, 100)	.963 (.033)
RTDM	3482	39	25 (23, 27)	50 (48, 51)	.902 (.033)
PLUMES	3482	39	10 (2, 17)	203 (198, 209)	.783 (.033)
COMPLEX/PFM	3456	39	16 (10, 22)	157 (154, 161)	.361 (.033)
SHORTZ	3486	39	-29 (-37, -20)	171 (167, 176)	.561 (.033)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 24-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.86	417	133	.223	.320	.013 (.012, .015)
COMPLEXII	.89	531	142	.205	.328	.009 (.007, .009)
4141	.94	100	96	.194	.327	.266 (.237, .296)
RTDM	.90	55	73	.384	.406	1.425 (1.295, 1.564)
PLUME5	.90	293	69	.222	.335	.054 (.049, .059)
COMPLEX/PFM	.93	156	52	.105	.316	.098 (.089, .107)
SHORTZ	.73	174	70	.324	.407	.071 (.064, .078)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                COMPARISON OF ALL OBSERVED AND PREDICTED
                 SO2 CONCENTRATION VALUES (UG/M**3)
                     PAIRED IN TIME AND LOCATION
                       (FOR VARIOUS DATA SETS)
                          MODEL: COMPLEX1
                 FOR THE 24-HOUR AVERAGING PERIOD
                       WESTVACO (1980/1981)

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        DATA SET          NUMBER         AVERAGE          AVERAGE          STANDARD
                            OF          OBSERVED        DIFFERENCE         DEVIATION
                          EVENTS          VALUE         (OBS-PRED)       OF RESIDUALS

--------------------------------------------------------------------------------------------------

        ALL                3463             39              -75               411
        STATION  1          317             57             -277               712
        STATION  2          287             22               21                18
        STATION  3          264             51             -147               478
        STATION  4          317             37              -56               317
        STATION  5          319             37              -11               200
        STATION  6          285             91             -499               688
        STATION  7          321             35                1               160
        STATION  8          336             32               23                66
        STATION  9          341             3[illegible]              15                79
        STATION 10          349             2[illegible]               9                27
        STATION 11          327             24               23                19
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                    COMPARISON OF ALL OBSERVED AND PREDICTED
                      SO2 CONCENTRATION VALUES (UG/M**3)
                          PAIRED IN TIME AND LOCATION
                            (FOR VARIOUS DATA SETS)
                               MODEL: COMPLEXII
                       FOR THE 24-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)

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        DATA SET          NUMBER        AVERAGE        AVERAGE         STANDARD
                            OF          OBSERVED      DIFFERENCE       DEVIATION
                          EVENTS         VALUE        (OBS-PRED)     OF RESIDUALS

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        ALL                3463           39             -81              525

        STATION  1          317           57            -309              971

        STATION  2          287           22              21               18

        STATION  3          264           50            -136              557

        STATION  4          317           37             -52              389

        STATION  5          319           37              -2              217

        STATION  6          285           91            -551             1167

        STATION  7          321           35              -3              227

        STATION  8          336           32              24               91

        STATION  9          341           30              13              107

        STATION 10          349           27               8               38

        STATION 11          327           24              23               19
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEX/PFM
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3456	39	16	157
STATION 1	316	57	-5	250
STATION 2	287	22	23	28
STATION 3	263	50	23	162
STATION 4	316	37	18	163
STATION 5	319	37	21	100
STATION 6	285	91	-12	390
STATION 7	320	35	23	72
STATION 8	335	32	27	47
STATION 9	340	30	22	53
STATION 10	349	20	14	22
STATION 11	326	24	23	21

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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: 4141
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3463	39	20	98
STATION 1	317	57	2	135
STATION 2	287	22	21	19
STATION 3	264	51	48	54
STATION 4	317	37	22	73
STATION 5	319	37	8	140
STATION 6	285	91	41	118
STATION 7	321	35	12	122
STATION 8	336	32	25	75
STATION 9	341	30	6	143
STATION 10	349	20	19	17
STATION 11	327	24	23	19

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: PLUMES
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3482	39	10	203
STATION 1	319	57	-29	272
STATION 2	289	22	21	19
STATION 3	265	50	27	122
STATION 4	318	37	25	79
STATION 5	321	37	22	124
STATION 6	287	90	-90	596
STATION 7	323	35	25	82
STATION 8	338	32	29	41
STATION 9	343	30	25	45
STATION 10	351	20	17	18
STATION 11	328	24	23	13

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: RTDM
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	2676	37	-43	251
STATION 1	258	56	-55	241
STATION 2	241	2[illegible]	3	43
STATION 3	223	47	-59	249
STATION 4	269	35	-83	289
STATION 5	268	36	-40	271
STATION 6	234	9[illegible]	-11	164
STATION 7	268	34	-119	513
STATION 8	284	31	-57	197
STATION 9	282	3[illegible]	-57	265
STATION 10	291	18	0	37
STATION 11	267	24	0	36

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: SHORTZ
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3486	39	-29	171
STATION 1	319	57	-137	267
STATION 2	269	22	16	28
STATION 3	265	56	-53	276
STATION 4	321	37	-21	135
STATION 5	321	37	12	71
STATION 6	287	90	-255	349
STATION 7	323	35	14	64
STATION 8	338	37	25	42
STATION 9	343	37	21	41
STATION 10	352	27	8	23
STATION 11	328	24	18	22

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                      COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                           (UNPAIRED IN TIME OR LOCATION)
                             FOR THE  1-HOUR AVERAGING PERIOD
                                 WESTVACO (1980/1981)
                            HOURS SELECTED FOR IMPACT MODEL RUNS
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     MODEL        AVERAGE       AVERAGE       DIFFERENCE         MEDIAN          VARIANCE        MAXIMUM
                  OBSERVED      PREDICTED    OF AVERAGES*      DIFFERENCE*      COMPARISON      FREQUENCY
                   VALUE         VALUE        (OBS-PRED)        (OBS-PRED)      (OBS/PRED)      DIFFERENCE
------------------------------------------------------------------------------------------------------------

   COMPLEXI         1792         11420          -9627             -8504            .015            1.00
                                          (-11043, -8212)  (-10169, -7752)  ( .006, .033)     ( .385)

   COMPLEXII        1792         20558         -18765            -18139            .002            1.00
                                          (-22874,-14557)  (-20821,-13630)  ( .001, .004)     ( .385)

   4141             1792          3430          -1637              -475            .011             .43
                                          ( -3257,   -17)  ( -1570,   237)  ( .005, .025)     ( .385)

   RTDM             1792          2031           -238               200            .096             .35
                                          (  -810,   332)  (  -255,   559)  ( .042, .217)     ( .385)

   PLUME5           1792          5413          -3620             -2470            .015             .88
                                          ( -5034, -2205)  ( -3835, -1617)  ( .006, .033)     ( .385)

   COMPLEX/PFM      1792          9011          -7218             -6433            .005             .84
                                          ( -9537, -4899)  ( -9785, -4617)  ( .002, .012)     ( .385)

   SHORTZ           1792          7448          -5655             -4404            .005             .80
                                          ( -7813, -3498)  ( -6859, -2151)  ( .003, .014)     ( .385)

   IMPACT           1786         17829         -16042             -4441            .000            1.00
                                          (-26484, -5600)  ( -8189, -3115)  ( .000, .001)     ( .385)


   * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                         SO2 CONCENTRATION VALUES (UG/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                          FOR THE  3-HOUR AVERAGING PERIOD
                               WESTVACO (1980/1981)
                        HOURS SELECTED FOR IMPACT MODEL RUNS
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   MODEL           AVERAGE      AVERAGE        DIFFERENCE        MEDIAN          VARIANCE       MAXIMUM
                  OBSERVED     PREDICTED      OF AVERAGES*     DIFFERENCE*      COMPARISON     FREQUENCY
                    VALUE        VALUE         (OBS-PRED)       (OBS-PRED)      (OBS/PRED)     DIFFERENCE
------------------------------------------------------------------------------------------------------

COMPLEXI             941         5318           -4375             -3571            .015           .92
                                            ( -5610, -3141)  ( -5253, -2634)  ( .007, .035)    ( .383)

COMPLEXII            941         7898           -6955             -6377            .005           .63
                                            ( -9077, -4834)  ( -9133, -4796)  ( .002, .012)    ( .383)

4141                 941         1277            -334               178            .053           .43
                                            ( -1010,   341)  (  -150,   396)  ( .023, .121)    ( .383)

RTD4                 941          834             107               305            .243           .52
                                            (  -230,   443)  (   -20,   509)  ( .107, .553)    ( .383)

PLUMES               941         1868            -925               -64            .024           .43
                                            ( -1918,    68)  (  -961,   352)  ( .011, .055)    ( .393)

COMPLEX/PFM          941         2871           -1928              -132            .011           .44
                                            ( -3378,  -479)  ( -2854,   431)  ( .005, .025)    ( .383)

SHORTZ               941         2669           -1727              -649            .026           .52
                                            ( -2675,  -779)  ( -1337,  -328)  ( .012, .055)    ( .383)

IMPACT               922         5693           -5770             -1356            .001           .53
                                            (-10860,  -680)  ( -2202,  -658)  ( .000, .002)    ( .383)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1876	-7556 (-12685, -2426)	.30	7171 (4932,13092)	10153	7767	.45	.56	.012 (.003, .049)
COMPLEXII	10	1876	-17123 (-28531, -5715)	.20	15949 (10969,29117)	21994	17253	.53	.65	.003 (.001, .011)
4141	10	1876	-3865 (-8676, 944)	.40	6725 (4625,12278)	7726	4354	.34	.32	.015 (.004, .059)
RTDM	10	1876	-164 (-1116, 787)	.70	1331 (915, 2430)	3250	893	.60	.73	.239 (.054,1.043)
PLUMES	10	1876	-3138 (-6573, 295)	.40	4892 (3303, 9767)	6076	3380	.55	.66	.026 (.005, .135)
COMPLEX/PFM	10	1876	-7520 (-13104, -1937)	.30	7806 (5369,14251)	10505	7318	.50	.54	.013 (.005, .042)
SHORTZ	10	1876	-6026 (-11029, -1023)	.10	6994 (4811,12769)	9663	6075	.59	.73	.013 (.003, .051)
IMPACT	10	1876	-43349 (-54239,-22589)	.00	29092 (20311,53115)	49131	43400	.57	.58	.001 (.000, .003)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1273	-3421 (-6652, -189)	.30	4518 (3128, 8249)	6035	3967	.37	.36	.013 (.004, .051)
COMPLEXII	10	1273	-6178 (-10765, -1590)	.30	6413 (4411,11708)	8900	5388	.48	.39	.008 (.002, .030)
4141	10	1273	-1074 (-2754, 604)	.60	2349 (1615, 4288)	3828	1632	.51	.54	.050 (.012, .201)
FTDM	10	1273	292 (-282, 867)	.80	804 (553, 1467)	3114	704	.45	.47	.441 (.110,1.779)
PLUMES	10	1273	-1031 (-3201, 1138)	.60	3033 (2085, 5538)	4194	1702	.48	.73	.032 (.008, .127)
COMPLEX/PFM	10	1273	-2684 (-5701, 331)	.40	4217 (2900, 7699)	5495	3176	.41	.54	.017 (.004, .069)
SHORTZ	10	1273	-1582 (-3434, 259)	.60	2589 (1781, 4726)	4105	1847	.41	.47	.044 (.011, .176)
IMPACT	10	1273	-23086 (-35063,-11110)	.00	15743 (11516,30569)	26895	23087	.73	.73	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                                     COMPARISON OF HIGHEST
                                     OBSERVED AND PREDICTED
                                SO2 CONCENTRATION VALUES (UG/M**3)
                          PAIRED BY STATION FOR THE  1 HOUR AVERAGING PERIOD
                                     WESTVACO (1980/1981)
                                HOURS SELECTED FOR IMPACT MODEL RUNS

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   MODEL      NUMBER    AVERAGE       AVERAGE        FRACTION   STANDARD    ROOT MEAN   AVERAGE    PEARSON    SPEARMAN    VARIANCE
                OF      OBSERVED    DIFFERENCE*         OF      DEVIATION*   SQUARE     ABSOLUTE    CORR.      CORR.     COMPARISON*
               DATA      VALUE                       POSITIVE      OF         ERROR     RESIDUAL    COEFF.     COEFF.    (OBS>PRED)
               PAIRS                                 RESIDUALS  RESIDUALS
                                                     (OBS>PRED)

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COMPLEXI        10       1876         -7556             .30        7171       10153       7767       .56        .56         .012
                                 (-12685, -2425)               ( 4932,13092)                                              (.003, .048)

COMPLEXII       10       1876        -17123             .20       15949       21994      17253       .53        .55         .003
                                 (-28531, -5715)               (10969,29117)                                              (.001, .011)

4141            10       1876         -3865             .40        6725        7726       4354       .34        .32         .015
                                 ( -8676,   944)               ( 4625,12278)                                              (.004, .059)

RTDM            10       1876          -164             .70        1331        3250        893       .60        .73         .239
                                 ( -1116,   787)               (  915, 2430)                                              (.054,1.043)

PLUMES          10       1876         -3138             .40        4892        6076       3380       .55        .55         .025
                                 ( -6573,   295)               ( 3303, 8767)                                              (.005, .105)

COMPLEX/PFM     10       1976         -7520             .30        7806       10505       7318       .50        .54         .013
                                 (-13104, -1937)               ( 5369,14251)                                              (.003, .042)

SHORTZ          10       1976         -6025             .10        6994        9663       6075       .59        .70         .013
                                 (-11029, -1023)               ( 4811,12763)                                              (.003, .051)

IMPACT          10       1876        -43399             .50       29892       49131      43400       .57        .58         .001
                                 (-54209,-22589)               (20311,53115)                                              (.000, .003)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1273	-3421 (-6652, -189)	.30	4518 (3108, 8249)	6036	3567	.37	.36	.013 (.004, .051)
COMPLEXII	10	1273	-6178 (-10765, -1590)	.30	6413 (4411,11708)	8800	5389	.48	.39	.008 (.002, .030)
4141	10	1273	-1674 (-2754, 604)	.60	2349 (1615, 4288)	3828	1532	.51	.54	.053 (.012, .201)
RTDM	10	1273	242 (-282, 867)	.80	804 (553, 1967)	3114	704	.45	.49	.441 (.110,1.779)
PLUMES	10	1273	-1031 (-3201, 1138)	.60	3033 (2085, 5538)	4194	1702	.48	.73	.032 (.008, .127)
COMPLEX/PFM	10	1273	-2684 (-5701, 331)	.40	4217 (2900, 7594)	5495	3175	.41	.54	.017 (.004, .069)
SHORTZ	10	1273	-1562 (-3434, 259)	.60	2589 (1781, 4726)	4105	1947	.41	.47	.044 (.011, .176)
IMPACT	10	1273	-23986 (-35863,-11110)	.00	16743 (11516,30567)	26989	23097	.73	.73	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                                   COMPARISON OF HIGHEST
                                   OBSERVED AND PREDICTED
                              SO2 CONCENTRATION VALUES (UG/M**3)
                     PAIRED BY STATION FOR THE  1 HOUR AVERAGING PERIOD
                                   WESTVACO (1980/1981)
                              HOURS SELECTED FOR IMPACT MODEL RUNS

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  MODEL     NUMBER   AVERAGE      AVERAGE        FRACTION   STANDARD    ROOT MEAN   AVERAGE    PEARSON    SPEARMAN    VARIANCE
              OF     OBSERVED   DIFFERENCE*         OF      DEVIATION*   SQUARE     ABSOLUTE    CORR.      CORR.     COMPARISON*
             DATA     VALUE                      POSITIVE      OF         ERROR     RESIDUAL    COEFF.     COEFF.     (OBS>PRED)
             PAIRS                               RESIDUALS  RESIDUALS
                                                 (OBS>PRED)

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COMPLEXI      10      1876         -7556           .30         7171       10153      7767        .66        .56         .012
                                (-12685, -2426)             ( 4932,13092)                                             (.003, .048)

COMPLEXII     10      1876        -17123           .20        15949       21994     17253        .63        .55         .005
                                (-28531, -5715)             (10969,29117)                                             (.001, .011)

4141          10      1876         -3865           .40         6725        7726      4354        .34        .32         .015
                                ( -8676,   944)             ( 4625,12278)                                             (.004, .039)

RTDM          10      1876          -164           .70         1331        3250       893        .60        .73         .239
                                ( -1116,   787)             (  915, 2930)                                             (.059,1.093)

PLUME5        10      1876         -3138           .40         4892        6076      3980        .55        .65         .026
                                ( -6573,   296)             ( 3303, 8767)                                             (.005, .135)

COMPLEX/PFM   10      1876         -7520           .30         7806       10505      7918        .60        .54         .013
                                (-13104, -1937)             ( 5369,14251)                                             (.005, .042)

SHORTZ        10      1876         -6026           .10         6994        9663      6975        .59        .73         .013
                                (-11029, -1023)             ( 4811,12769)                                             (.005, .051)

IMPACT        10      1876        -43399           .00        29092       49131     43400        .57        .58         .001
                                (-64209,-22589)             (20011,53115)                                             (.000, .003)


 * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1273	-3421 (-6652, -189)	.30	4518 (3108, 8249)	6036	3567	.37	.36	.015 (.004, .051)
COMPLEXII	10	1273	-6178 (-10765, -1590)	.30	5413 (4411,11709)	8800	5389	.48	.39	.008 (.002, .030)
4141	10	1273	-1674 (-2754, 604)	.60	2349 (1615, 4286)	3828	1532	.51	.54	.050 (.012, .201)
FTDM	10	1273	292 (-282, 867)	.80	804 (553, 1467)	3114	704	.45	.49	.441 (.110,1.779)
PLUMES	10	1273	-1031 (-3201, 1139)	.60	3033 (2086, 5538)	4194	1702	.48	.73	.032 (.008, .127)
COMPLEX/PFM	10	1273	-2684 (-5701, 331)	.40	4217 (2900, 7599)	5495	3176	.41	.54	.017 (.004, .069)
SHORTZ	10	1273	-1582 (-3434, 259)	.60	2589 (1781, 4726)	4105	1947	.41	.47	.044 (.011, .176)
IMPACT	10	1273	-23086 (-35063,-11110)	.00	16743 (11516,30569)	26989	23087	.73	.79	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1876	-7556 (-12685, -2426)	.30	7171 (4932,13092)	10153	7767	.55	.56	.012 (.003, .049)
COMPLEXII	10	1876	-17123 (-28531, -5715)	.20	15949 (10969,29117)	21994	17253	.53	.55	.003 (.001, .011)
4141	10	1876	-3865 (-8676, 944)	.40	6725 (4625,12278)	7726	4354	.34	.32	.015 (.004, .059)
RTDM	10	1876	-164 (-1116, 787)	.70	1331 (915, 2430)	3250	893	.60	.73	.239 (.054,1.043)
PLUMES	10	1876	-3138 (-6573, 296)	.40	4892 (3303, 8767)	6076	3380	.55	.55	.025 (.005, .125)
COMPLEX/PFM	10	1876	-7520 (-13104, -1937)	.30	7806 (5369,14251)	10505	7318	.60	.54	.013 (.003, .042)
SHORTZ	10	1876	-6025 (-11029, -1023)	.10	6994 (4811,12769)	9663	6075	.59	.73	.013 (.003, .051)
IMPACT	10	1876	-43399 (-54209,-22589)	.50	29892 (20311,53115)	49131	43400	.57	.58	.001 (.000, .003)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1273	-3421 (-6652, -189)	.30	4518 (3108, 8249)	6036	3567	.37	.36	.015 (.004, .051)
COMPLEXII	10	1273	-6178 (-10765, -1590)	.30	6415 (4411,11708)	8900	5389	.48	.39	.008 (.002, .030)
4141	10	1273	-1074 (-2754, 604)	.60	2349 (1615, 4288)	3828	1632	.51	.54	.053 (.012, .201)
FTDM	10	1273	292 (-282, 867)	.80	804 (553, 1967)	3114	704	.45	.47	.441 (.110,1.779)
PLUMES	10	1273	-1031 (-3201, 1138)	.60	3033 (2085, 5538)	4194	1702	.49	.73	.032 (.008, .127)
COMPLEX/PFM	10	1273	-2684 (-5701, 331)	.40	4217 (2900, 7599)	5495	3176	.41	.34	.017 (.004, .069)
SHORTZ	10	1273	-1582 (-3434, 259)	.60	2589 (1761, 4726)	4105	1947	.41	.47	.044 (.011, .176)
IMPACT	10	1273	-23086 (-35063,-11110)	.00	16743 (11516,30569)	26989	23087	.73	.73	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 24 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	326	-626 (-1447, 195)	.40	1149 (790, 2097)	3245	721	.56	.79	.011 (.003, .043)
COMPLEXII	10	326	-1089 (-2350, 172)	.40	1764 (1213, 3220)	3566	1214	.50	.71	.005 (.001, .013)
4141	10	326	44 (-164, 252)	.80	292 (201, 532)	3027	235	.16	.33	.195 (.046, .787)
RTDM	10	325	45 (-79, 170)	.80	175 (126, 320)	3020	154	.78	.91	.243 (.051, .995)
PLUMES	10	326	-257 (-1069, 554)	.60	1135 (781, 2072)	3195	532	.34	.64	.011 (.003, .045)
COMPLEX/PFM	10	325	-367 (-1003, 258)	.40	893 (611, 1527)	3140	531	.52	.64	.019 (.004, .071)
SHORTZ	10	326	-255 (-737, 225)	.60	673 (463, 1229)	3086	428	.64	.84	.029 (.007, .119)
IMPACT	10	325	-3432 (-5061, -1803)	.00	2279 (1567, 4159)	4304	3433	.32	.27	.003 (.001, .012)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 1 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1654	-5652 (-10085, -1221)	.30	6197 (4262,11314)	8540	5671	.53	.45	.013 (.003, .053)
COMPLEXII	10	1654	-10808 (-19398, -2217)	.40	12909 (8260,21926)	15274	11526	.45	.41	.004 (.001, .015)
4141	10	1654	-1725 (-4008, 558)	.50	3193 (2196, 5829)	4487	2556	.55	.54	.043 (.011, .191)
RTDM	10	1654	112 (-726, 951)	.60	1173 (807, 2142)	2198	332	.48	.43	.317 (.079,1.279)
PLUMES	10	1654	-586 (-3275, 2097)	.70	3755 (2584, 6858)	4577	2208	.33	.37	.055 (.029, .147)
COMPLEX/PFM	10	1654	-4490 (-9392, 411)	.40	6853 (4714,12513)	8115	5040	.52	.57	.011 (.003, .044)
SHORTZ	10	1654	-2390 (-5507, 725)	.40	4357 (2997, 7255)	5461	2779	.41	.45	.027 (.007, .107)
IMPACT	10	1654	-33198 (-45216,-15190)	.60	20995 (14441,38231)	34524	30199	.52	.54	.001 (.000, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 3 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	1021	-2036 (-3848, -224)	.30	2533 (1742, 4624)	4256	2185	.65	.71	.033 (.008, .132)
COMPLEXII	10	1021	-4219 (-8293, -145)	.40	5695 (3917,10398)	7198	4659	.60	.74	.007 (.002, .030)
4141	10	1021	-82 (-676, 511)	.60	930 (571, 1516)	3108	581	.76	.89	.193 (.049, .802)
RTDM	10	1021	206 (-224, 637)	.70	602 (414, 1099)	3070	480	.60	.64	.453 (.115,1.884)
PLUMES	10	1021	-129 (-1725, 1452)	.60	2225 (1530, 4362)	3627	1251	.42	.59	.045 (.011, .137)
COMPLEX/PFM	10	1021	-1374 (-3235, 485)	.50	2601 (1789, 4745)	4043	1928	.73	.83	.031 (.008, .124)
SHORTZ	10	1021	-987 (-2688, 715)	.60	2378 (1656, 4341)	3522	1442	.53	.67	.039 (.010, .156)
IMPACT	10	1021	-11931 (-17150, -6712)	.00	7297 (5019,13322)	13494	11932	.53	.50	.005 (.001, .019)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF SECOND HIGHEST
OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED BY STATION FOR THE 24 HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF DATA PAIRS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE*	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	STANDARD DEVIATION* OF RESIDUALS	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORR. COEFF.	SPEARMAN CORR. COEFF.	VARIANCE COMPARISON* (OBS>PRED)
COMPLEXI	10	251	-366 (-956, 224)	.40	826 (566, 1506)	3126	425	.72	.92	.015 (.004, .058)
COMPLEXII	10	251	-337 (-726, 53)	.40	543 (373, 991)	3072	462	.78	.98	.030 (.008, .122)
4141	10	251	140 (26, 253)	.90	159 (109, 290)	3021	189	.34	.56	.453 (.115,1.875)
RTDM	10	251	106 (22, 191)	.90	116 (81, 215)	3019	145	.74	.90	.393 (.097,1.574)
PLUMES	10	251	105 (-53, 264)	.90	222 (153, 406)	3023	204	.65	.94	.155 (.038, .515)
COMPLEX/PFM	10	251	-138 (-548, 272)	.80	573 (394, 1047)	3062	239	.73	.91	.028 (.007, .113)
SHORTZ	10	251	-69 (-305, 167)	.70	331 (227, 604)	3031	190	.79	.99	.072 (.017, .242)
IMPACT	10	251	-2148 (-3047, -1250)	.00	1256 (864, 2298)	3519	2149	.21	.25	.007 (.002, .023)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                COMPARISON OF HIGHEST OBSERVED AND PREDICTED
                  SO2 CONCENTRATION VALUES (UG/M**3)
                   EVENT-BY-EVENT (PAIRED IN TIME)
                    FOR THE  1-HOUR AVERAGING PERIOD
                        WESTVACO (1980/1981)
                  HOURS SELECTED FOR IMPACT MODEL RUNS
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 MODEL             NUMBER       AVERAGE        AVERAGE          STANDARD         MAXIMUM
                     OF         OBSERVED      DIFFERENCE*      DEVIATION*       FREQUENCY
                   EVENTS        VALUE        (OBS-PRED)      OF RESIDUALS      DIFFERENCE
--------------------------------------------------------------------------------------------

 COMPLEXI            460          373            -795             3258             .352
                                          ( -1331,  -259)   ( 3062,  3485)    (  .090)

 COMPLEXII           461          372           -1136             5436             .357
                                          ( -1790,  -482)   ( 5108,  5814)    (  .090)

 4141                461          372             128             1269             .352
                                          (   -27,   283)   ( 1193,  1358)    (  .090)

 RTDM                461          372             189              682             .531
                                          (    75,   301)   (  641,   730)    (  .090)

 PLUMES              461          372            -135             1657             .557
                                          (  -457,   198)   ( 1557,  1772)    (  .090)

 COMPLEX/PFM         461          372            -236             2572             .333
                                          (  -646,   174)   ( 2417,  2751)    (  .090)

 SHORTZ              463          370            -323             2098             .432
                                          (  -599,   -47)   ( 1962,  2233)    (  .089)

 IMPACT              418          363           -1050             7452             .585
                                          ( -2278,   177)   ( 5982,  7993)    (  .094)

 * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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                    COMPARISON OF HIGHEST OBSERVED AND PREDICTED
                       SO2 CONCENTRATION VALUES (UG/M**3)
                         EVENT-BY-EVENT (PAIRED IN TIME)
                        FOR THE  3-HOUR AVERAGING PERIOD
                              WESTVACO (1980/1981)
                       HOURS SELECTED FOR IMPACT MODEL RUNS
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   MODEL            NUMBER        AVERAGE         AVERAGE          STANDARD        MAXIMUM
                      OF          OBSERVED       DIFFERENCE*       DEVIATION*      FREQUENCY
                    EVENTS         VALUE         (OBS-PRED)      OF RESIDUALS     DIFFERENCE
-------------------------------------------------------------------------------------------------

   COMPLEXI           150           349             -762             2496              .757
                                              ( -1290,  -244)   ( 2245,  2821)    (   .157)

   COMPLEXII          150           349            -1100             3664              .773
                                              ( -1755,  -443)   ( 3296,  4142)    (   .157)

   4141               150           349              124              856              .789
                                              (   -41,   288)   (  770,   969)    (   .157)

   RTDM               151           347              179              524              .503
                                              (    55,   293)   (  471,   592)    (   .157)

   PLUMES             152           344             -111             1339              .467
                                              (  -575,   353)   ( 1205,  1512)    (   .155)

   COMPLEX/PFM        152           344             -205             1858              .730
                                              (  -581,   170)   ( 1672,  2098)    (   .155)

   SHORTZ             152           344             -301             1350              .335
                                              (  -574,   -28)   ( 1215,  1525)    (   .155)

   IMPACT             137           338            -1048             5786              .328
                                              ( -2119,    19)   ( 5180,  6580)    (   .164)

 * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF HIGHEST OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 24-HOUR AVERAGING PERIOD
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	20	269	-564 (-1049, -78)	1159 (888, 1733)	.500 (.430)
COMP_EXII	20	269	-693 (-1222, -164)	1473 (1129, 2203)	.500 (.430)
4141	20	269	123 (42, 203)	248 (190, 370)	.550 (.430)
RTDM	20	269	138 (40, 235)	211 (162, 316)	.700 (.430)
PLUMES	20	269	-115 (-501, 272)	836 (641, 1250)	.500 (.430)
COMP_EX/PFM	20	269	-90 (-397, 217)	796 (610, 1190)	.550 (.430)
SHORTZ	20	269	-242 (-499, 15)	524 (402, 784)	.400 (.430)
IMPACT	18	261	-958 (-2406, 490)	2054 (1554, 3164)	.589 (.453)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (U3/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODE.	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	2477	203	-59 (-126, 11)	1638 (1594, 1685)	.359 (.039)
COMP_EXII	2476	204	-92 (-191, 6)	2471 (2404, 2542)	.354 (.039)
4141	2478	203	145 (115, 174)	724 (705, 745)	.354 (.039)
RTDM	2531	199	137 (120, 154)	409 (398, 420)	.304 (.038)
PLUMES	2508	201	100 (69, 131)	783 (762, 805)	.370 (.038)
COMPLEX/PFM	2474	204	67 (18, 117)	1267 (1232, 1303)	.348 (.039)
SHORTZ	2595	193	23 (-16, 63)	991 (965, 1019)	.740 (.038)
IMPACT	2526	180	-517 (-797, -437)	4627 (4504, 4753)	.305 (.038)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.97	1639	453	-.002	-.009	.041 (.037, .045)
COMPLEXII	.97	2472	498	.018	-.060	.017 (.015, .019)
4141	.97	739	250	.062	-.074	.234 (.212, .259)
RTDM	.90	431	217	.125	.058	1.180 (1.059, 1.303)
PLUMES	.92	789	269	.109	-.039	.195 (.157, .204)
COMPLEX/PFM	.96	1258	327	.017	.013	.069 (.053, .077)
SHORTZ	.82	991	306	.051	-.091	.111 (.101, .123)
IMPACT	.70	4557	879	-.020	.022	.005 (.004, .005)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 3-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 1)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE* (OBS-PRED)	STANDARD DEVIATION* OF RESIDUALS	MAXIMUM FREQUENCY DIFFERENCE
COMP_EXI	861	193	-58 (-160, 44)	1221 (1166, 1282)	.332 (.066)
COMPLEXII	858	193	-92 (-220, 37)	1597 (1621, 1782)	.337 (.065)
4141	860	193	137 (102, 171)	475 (454, 499)	.333 (.065)
RTDM	883	189	129 (100, 157)	321 (307, 337)	.745* (.065)
PLUMES	877	189	94 (15, 172)	516 (588, 546)	.328 (.065)
COMP_EX/PFM	867	191	62 (-8, 132)	890 (850, 934)	.311 (.065)
SHORTZ	913	182	21 (-35, 77)	689 (655, 723)	.553 (.064)
IMPACT	865	173	-591 (-859, -332)	3669 (3505, 3852)	.477 (.065)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 3-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.94	1222	421	-.019	-.021	.048 (.042, .054)
COMPLEXII	.95	1598	457	.005	-.051	.024 (.021, .027)
4141	.95	494	250	.062	-.048	.392 (.345, .445)
RTDM	.88	346	194	.134	.105	1.255 (1.115, 1.430)
PLUMES	.90	623	242	.132	-.032	.189 (.157, .219)
COMPLEX/PFM	.94	892	350	.009	.022	.092 (.081, .104)
SHORTZ	.77	659	270	.074	-.071	.150 (.133, .169)
IMPACT	.69	1716	832	.000	.102	.035 (.024, .065)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                         COMPARISON OF ALL OBSERVED AND PREDICTED
                          SO2 CONCENTRATION VALUES (UG/M**3)
                              PAIRED IN TIME AND LOCATION
                             FOR THE 24-HOUR AVERAGING PERIOD
                                 SUMMARY TABLE (PART 1)
                                  WESTVACO (1980/1981)
                            HOURS SELECTED FOR IMPACT MODEL RUNS

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     MODEL             NUMBER          AVERAGE          AVERAGE          STANDARD          MAXIMUM
                         OF           OBSERVED        DIFFERENCE*       DEVIATION*        FREQUENCY
                       EVENTS           VALUE         (OBS-PRED)      OF RESIDUALS        DIFFERENCE

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     COMP_EXI           165             124                -33              502              .300
                                                    (  -117,    50)   (  454,   564)     (  .150)

     COMP_EXII          165             124                -44              615              .305
                                                    (  -139,    47)   (  556,   691)     (  .150)

     4141               165             124                 95              143              .319
                                                    (    72,   117)   (  129,   160)     (  .150)

     RTDM               165             124                 86              121              .555
                                                    (    57,   105)   (  110,   136)     (  .150)

     PLUMES             165             124                 61              311              .721
                                                    (     8,   114)   (  281,   350)     (  .150)

     COMPLEX/PFM        165             124                 43              344              .775
                                                    (    -5,    91)   (  311,   385)     (  .150)

     SHORTZ             165             124                 15              273              .391
                                                    (   -39,    65)   (  246,   305)     (  .150)

     IMPACT             150             122               -435             1225              .380
                                                    (  -543,  -226)   ( 1102,  1385)     (  .157)

   * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
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COMPARISON OF ALL OBSERVED AND PREDICTED
SO2 CONCENTRATION VALUES (UG/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 24-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
WESTVACO (1980/1981)
HOURS SELECTED FOR IMPACT MODEL RUNS

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.82	502	222	.007	.170	.050 (.039, .065)
COMPLEXII	.85	615	245	.019	.222	.033 (.025, .042)
4141	.95	171	123	.126	.299	1.075 (.829, 1.398)
RTDM	.92	148	105	.354	.490	1.127 (.959, 1.454)
PLUME5	.90	316	135	.284	.235	.115 (.058, .149)
COMPLEX/PFM	.90	345	165	.075	.333	.108 (.033, .140)
SHORTZ	.80	272	143	.315	.427	.147 (.113, .191)
IMPACT	.59	1296	530	.361	.551	.009 (.005, .016)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

APPENDIX C

STATISTICAL TABLE OF MODEL PERFORMANCE FOR CINDER CONE BUTTE

Table	Page
Cinder Cone Butte Comparison of 25 Highest	C-1
Cinder Cone Butte Comparison of Highest by Event	C-10
Cinder Cone Butte Comparison of All Events Paired in Space and Time	C-20

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

MODEL	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	MEDIAN DIFFERENCE* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)	MAXIMUM FREQUENCY DIFFERENCE
COMPLEXI	66	165	-38 (-60, -15)	-31 (-56, -18)	.532 (.234,1.207)	.52 (.385)
COMPLEXII	66	250	-183 (-231, -135)	-148 (-207, -115)	.084 (.037, .191)	.95 (.385)
4141	66	196	-129 (-154, -100)	-120 (-154, -92)	.255 (.112, .578)	.92 (.385)
RTDM	66	67	0 (-23, 22)	5 (-12, 24)	.475 (.210,1.080)	.23 (.385)
PLUMES	66	177	-110 (-165, -55)	-57 (-103, -45)	.062 (.027, .140)	.63 (.385)
COMPLEX/PFM	66	166	-99 (-135, -63)	-87 (-121, -57)	.151 (.067, .343)	.63 (.385)
SHORTZ	66	139	-72 (-143, -1)	-19 (-30, -3)	.037 (.016, .084)	.35 (.385)
IMPACT	66	34	31 (15, 47)	27 (13, 42)	2.545 (1.165,5.603)	.73 (.385)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                 COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                 RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                              FOR VARIOUS DATA SETS
                                MODEL: COMPLEX I
                         FOR THE  1-HOUR AVERAGING PERIOD
                              CINDER CONE BUTTE (1980)
------------------------------------------------------------------------------------------

          DATA SETS              AVERAGE          AVERAGE          DIFFERENCE         VARIANCE
                                 OBSERVED        PREDICTED        OF AVERAGES*       COMPARISON
                                  VALUE            VALUE           (OBS-PRED)        (OBS/PRED)
------------------------------------------------------------------------------------------

          ALL                       66              105                -38               .532
                                                                ( -60,    -16)    ( .234,1.207)

          RECEPTOR ELEVATION RELATIVE
           TO SOURCE RELEASE HEIGHT

            <-10. M                 39               64                -24               .351
            -10. M TO 10. M         51               93                -41               .579
            10. M TO 30. M          41               74                -32               .471
            >30. M                  43               59                -14              1.270
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: COMPLEXII
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	65	25[illegible]	-183 (-231, -135)	.084 (.037, .131)
RECEPTOR ELEVATION RELATIVE TO SOURCE RELEASE HEIGHT				
<-10. M	39	114	-74	.039
-10. M TO 10. M	51	1[illegible]1	-138	.083
10. M TO 30. M	41	147	-105	.189
>30. M	43	146	-102	.158

```
              COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
              RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                      (UNPAIRED IN TIME OR LOCATION)
                           FOR VARIOUS DATA SETS
                            MODEL: COMPLEX/PFM
                       FOR THE  1-HOUR AVERAGING PERIOD
                          CINDER CONE BUTTE (1980)
-----------------------------------------------------------------------------------------------

      DATA SETS               AVERAGE         AVERAGE         DIFFERENCE          VARIANCE
                              OBSERVED        PREDICTED       OF AVERAGES*        COMPARISON
                               VALUE           VALUE          (OBS-PRED)          (OBS/PRED)

-----------------------------------------------------------------------------------------------

      ALL                        66             165               -99                .151
                                                             (  -135,    -63)     ( .067, .343)

      RECEPTOR ELEVATION RELATIVE
       TO SOURCE RELEASE HEIGHT

        <-10. M                  39              67               -27                .389
        -10. M TO 10. M          51             129               -77                .137
         10. M TO 30. M          41             115               -73                .092
        >30. M                   43             114               -69                .134
```

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                    RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                               FOR VARIOUS DATA SETS
                                   MODEL: 4141
                          FOR THE  1-HOUR AVERAGING PERIOD
                              CINDER CONE BUTTE (1980)

---------------------------------------------------------------------------------------------
       DATA SETS               AVERAGE          AVERAGE         DIFFERENCE         VARIANCE
                               OBSERVED        PREDICTED       OF AVERAGES*       COMPARISON
                                VALUE            VALUE          (OBS-PRED)        (OBS/PRED)
---------------------------------------------------------------------------------------------

       ALL                         66              195               -129              .255
                                                              (  -158,  -100)     ( .112, .578)


       RECEPTOR ELEVATION RELATIVE
        TO SOURCE RELEASE HEIGHT

          <-10. M                  39               64                -24              .194
          -10. M TO 10. M          51              142                -90              .278
          10. M TO 30. M           41              155               -113              .161
          >30. M                   43              134                -89              .251
```

COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
(UNPAIRED IN TIME OR LOCATION)
FOR VARIOUS DATA SETS
MODEL: PLUMES
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SETS	AVERAGE OBSERVED VALUE	AVERAGE PREDICTED VALUE	DIFFERENCE OF AVERAGES* (OBS-PRED)	VARIANCE COMPARISON (OBS/PRED)
ALL	66	177	-110 (-165, -55)	.062 (.027, .140)
RECEPTOR ELEVATION RELATIVE TO SOURCE RELEASE HEIGHT				
<-10. M	39	106	-67	.027
-10. M TO 10. M	51	103	-51	.243
10. M TO 30. M	41	99	-57	.180
>30. M	43	112	-67	.678

231<

```
                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                    RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                          (UNPAIRED IN TIME OR LOCATION)
                               FOR VARIOUS DATA SETS
                                    MODEL: RTDM
                          FOR THE  1-HOUR AVERAGING PERIOD
                               CINDER CONE BUTTE (1980)
---------------------------------------------------------------------------------------------------
         DATA SETS           AVERAGE         AVERAGE        DIFFERENCE         VARIANCE
                             OBSERVED        PREDICTED      OF AVERAGES,       COMPARISON
                              VALUE           VALUE         (OBS-PRED)         (OBS/PRED)
---------------------------------------------------------------------------------------------------
         ALL                   65              67               -2                .332
                                                           (  -27,    25)     ( .146, .754)

         RECEPTOR ELEVATION RELATIVE
          TO SOURCE RELEASE HEIGHT

           <-10. M             39              35                4                .166
           -10. M TO 10. M     51              50                1               1.053
           10. M TO 30. M      41              43               -1                .633
           >30. M              43              43                0               1.098
```

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                    COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                    RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                             (UNPAIRED IN TIME OR LOCATION)
                                  FOR VARIOUS DATA SETS
                                     MODEL: SHORTZ
                            FOR THE  1-HOUR AVERAGING PERIOD
                                CINDER CONE BUTTE (1980)
---------------------------------------------------------------------------------------------------------
               DATA SETS                AVERAGE          AVERAGE          DIFFERENCE         VARIANCE
                                        OBSERVED         PREDICTED        OF AVERAGES,       COMPARISON
                                        VALUE            VALUE            (OBS-PRED)         (OBS/PRED)
---------------------------------------------------------------------------------------------------------

               ALL                         66              139                -72               .037
                                                                        ( -143,    -1)     ( .016, .084)

               RECEPTOR ELEVATION RELATIVE
                TO SOURCE RELEASE HEIGHT

                 <-10. M                   39               77             [illegible]          .419
                 -10. M TO 10. M           51               94                -42               .141
                 10. M TO 30. M            41               93                -51               .021
                 >30. M                    43               79                -34               .071
                COMPARISON OF 25 HIGHEST OBSERVED AND PREDICTED
                RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                       (UNPAIRED IN TIME OR LOCATION)
                           FOR VARIOUS DATA SETS
                              MODEL: IMPACT
                     FOR THE  1-HOUR AVERAGING PERIOD
                         CINDER CONE BUTTE (1980)
------------------------------------------------------------------------------------------------
        DATA SETS             AVERAGE         AVERAGE        DIFFERENCE        VARIANCE
                              OBSERVED        PREDICTED     OF AVERAGES*       COMPARISON
                               VALUE           VALUE         (OBS-PRED)        (OBS/PRED)
------------------------------------------------------------------------------------------------

        ALL                      65              34              31               2.645
                                                            (   16,   47)   (1.165,6.003)


        RECEPTOR ELEVATION RELATIVE
         TO SOURCE RELEASE HEIGHT

          <-10. M                39              33               6               1.250
          -10. M TO 10. M        51              20              31              16.390
          10. M TO 30. M         41              12              29              21.332
          >30. M                 43              10              34              23.097
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                    COMPARISON OF HIGHEST OBSERVED AND PREDICTED
                  RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                            EVENT-BY-EVENT (PAIRED IN TIME)
                            FOR THE  1-HOUR AVERAGING PERIOD
                                       PART 1
                                CINDER CONE BUTTE (1980)
-------------------------------------------------------------------------------------------------
*MODEL          NUMBER       AVERAGE         AVERAGE          STANDARD         MAXIMUM
                  OF         OBSERVED      DIFFERENCE*       DEVIATION*       FREQUENCY
                EVENTS        VALUE        (OBS-PRED)      OF RESIDUALS      DIFFERENCE
-------------------------------------------------------------------------------------------------
COMPLEXI          104          25            -16               41              .212
                                       (  -25,    -6)    (  36,    48)     (  .183)
COMP_EXII         104          25            -68              103              .442
                                       (  -95,   -39)    (  91,   120)     (  .183)
4141              104          25            -47               75              .345
                                       (  -67,   -26)    (  66,    87)     (  .189)
RTDM              104          25              0               30              .387
                                       (   -8,     9)    (  26,    35)     (  .183)
PLUMES            104          25            -40               98              .413
                                       (  -62,   -18)    (  78,   122)     (  .183)
COMPLEX/PFM       104          25            -34               46              .298
                                       (  -51,   -16)    (  38,    76)     (  .183)
SHORTZ            104          25            -20               94              .135
                                       (  -40,     0)    (  83,   110)     (  .183)
IMPACT            104          25             13               26              .299
                                       (    3,    20)    (  23,    31)     (  .183)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
```

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (PAIRED IN TIME)
FOR THE 1-HOUR AVERAGING PERIOD
PART 2
CINDER CONE BUTTE (1980)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.43	44	29	.454	.331	.397 (.287, .550)
COMPLEXII	.26	123	74	.345	.317	.068 (.049, .094)
4141	.36	88	55	.389	.365	.125 (.090, .173)
RTDM	.53	30	19	.399	.510	.623 (.450, .864)
PLUME5	.31	96	47	.278	.439	.097 (.070, .133)
COMPLEX/PFM	.30	74	42	.305	.496	.144 (.104, .199)
SHORTZ	.48	96	35	.256	.474	.085 (.062, .119)
IMPACT	.72	29	19	.414	.397	3.229 (2.315, 4.494)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: COMPLEX1
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-16	41	.454
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	-32	62	.188
H=15. M TO 26. M	12	27	-43	37	.733
H> 25. M	9	69	-13	55	.567
DISTANCE > 900. M					
H< 15. M	9	37	14	23	.649
H=15. M TO 26. M	46	19	-13	44	-.070
H> 25. M	24	13	-8	24	-.127
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	52	29	-27	47	.488
2.5 TO 5. M/S	27	22	-1	25	-.013
> 5. M/S	15	22	5	13	.464
2. STABILITY GROUP					
CLASS C+D	30	31	4	36	.529
CLASS E	38	26	-25	45	.556
CLASS F	36	22	-21	36	.351

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: COMPLEXII
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-68	143	.345
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	-176	154	.128
H=16. M TO 26. M	12	27	-55	43	.439
H> 26. M	9	69	-145	145	.417
DISTANCE > 900. M					
H< 15. M	6	37	-4	24	.691
H=16. M TO 26. M	46	19	-72	114	-.266
H> 26. M	24	13	-41	61	-.124
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	-97	121	.352
2.5 TO 5. M/S	27	22	-31	49	.645
> 5. M/S	15	22	-15	19	.453
2. STABILITY GROUP					
CLASS C+D	30	31	-9	36	.658
CLASS E	38	26	-97	127	.524
CLASS F	36	22	-86	96	.172

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: COMPLEX/PFM
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-34	65	.505
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	-68	63	.247
H=16. M TO 26. M	12	27	-47	45	.707
H> 26. M	9	59	-93	121	.577
DISTANCE > 900. M					
H< 15. M	9	27	5	23	.657
H=16. M TO 26. M	46	19	-32	52	-.099
H> 26. M	24	13	-14	45	-.092
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	-55	75	.534
2.5 TO 5. M/S	27	22	-4	25	.039
> 5. M/S	15	22	0	1[illegible]	.625
2. STABILITY GROUP					
CLASS C+D	30	31	-6	29	.631
CLASS E	38	26	-37	73	.573
CLASS F	36	22	-53	73	.393

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: 4141
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-47	75	.389
A) RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	8	59	-92	71	.216
H=16. M TO 26. M	12	27	-57	73	.625
H> 25. M	9	69	-92	[illegible]	.316
DISTANCE > 900. M					
H< 15. M	9	37	5	19	.867
H=15. M TO 26. M	46	19	-51	84	-.033
H> 25. M	24	13	-24	43	-.191
METEOROLOGICAL CONDITION					
A. WIND SPEED					
< 2.5 M/S	52	29	-73	85	.492
2.5 TO 5. M/S	27	22	-13	33	.264
> 5. M/S	15	22	-9	25	.430
B. STABILITY GROUP					
CLASS C+D	35	31	1	29	.639
CLASS E	36	26	-49	69	.575
CLASS F	36	22	-84	85	.514

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: PLUMES
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-40	68	.278
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	-204	253	-.033
H=16. M TO 26. M	12	27	-49	45	.437
H> 25. M	9	69	-13	29	.918
DISTANCE > 900. M					
H< 16. M	9	37	2	25	.731
H=16. M TO 26. M	46	19	-47	95	-.038
H> 25. M	24	13	-18	25	.151
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	-55	108	.267
2.5 TO 5. M/S	27	22	-26	42	.158
> 5. M/S	15	22	-12	18	.431
2. STABILITY GROUP					
CLASS C+D	30	31	-25	78	.651
CLASS E	38	25	-71	131	.221
CLASS F	36	22	-23	47	.298

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: RTDM
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	1	32	.551
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	46	34	-.699
H=16. M TO 26. M	12	27	-2	42	.367
H> 25. M	9	69	-31	55	.558
DISTANCE > 900. M					
H< 15. M	5	37	23	24	.598
H=16. M TO 26. M	46	19	2	17	.411
H> 25. M	29	13	-4	15	.282
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	-3	13	.549
2.5 TO 5. M/S	27	22	4	15	.623
> 5. M/S	15	22	7	12	.569
2. STABILITY GROUP					
CLASS C+D	30	31	5	28	.665
CLASS E	38	26	1	38	.535
CLASS F	36	22	-4	25	.435

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: SHORTZ
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	-25	94	.256
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	37	36	-.263
H=15. M TO 26. M	12	27	-10	47	.474
H> 25. M	9	69	-115	112	.155
DISTANCE > 900. M					
H< 15. M	9	37	24	22	.724
H=15. M TO 26. M	46	19	-3	13	.537
H> 25. M	24	13	-48	165	.549
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	-14	57	.520
2.5 TO 5. M/S	27	22	-17	43	.314
> 5. M/S	15	22	-48	213	-.128
2. STABILITY GROUP					
CLASS C+D	30	31	-3	27	.775
CLASS E	38	26	-13	52	.484
CLASS F	36	22	-42	148	.123

COMPARISON OF HIGHEST OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
EVENT-BY-EVENT (FOR VARIOUS DATA SETS)
MODEL: IMPACT
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS	PEARSON CORRELATION COEFFICIENT
HIGHEST CONCENTRATION EVENT BY EVENT	104	26	13	26	.414
BY RELEASE DISTANCE/ RELEASE HEIGHT					
DISTANCE < 900. M					
H< 15. M	4	59	42	28	.471
H=15. M TO 26. M	12	27	9	32	.369
H> 25. M	9	69	37	49	.458
DISTANCE > 900. M					
H< 15. M	9	37	30	24	.893
H=15. M TO 26. M	46	19	7	21	-.063
H> 25. M	24	13	4	12	.016
METEOROLOGICAL CONDITION					
1. WIND SPEED					
< 2.5 M/S	62	29	11	31	.433
2.5 TO 5. M/S	27	22	15	21	-.275
> 5. M/S	15	22	15	13	.711
2. STABILITY GROUP					
CLASS C+D	38	31	21	33	.452
CLASS E	38	26	11	23	.459
CLASS F	36	22	7	24	.428

```
                    COMPARISON OF ALL OBSERVED AND PREDICTED
               RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                          PAIRED IN TIME AND LOCATION
                        FOR THE  1-HOUR AVERAGING PERIOD
                            SUMMARY TABLE (PART I)
                            CINDER CONE BUTTE (1980)
------------------------------------------------------------------------------------------------------------
   MODEL           NUMBER          AVERAGE          AVERAGE             STANDARD            MAXIMUM
                     OF            OBSERVED        DIFFERENCE*         DEVIATION*          FREQUENCY
                   EVENTS           VALUE          (OBS-PRED)         OF RESIDUALS         DIFFERENCE
------------------------------------------------------------------------------------------------------------
                                                       -6                  20                .348
   COMPLEX I        3836              5          (  -5,    -5)      (  20,     21)      (  .031)

                                                       -6                  34                .293
   COMPLEX II       3836              5          (  -7,    -5)      (  34,     35)      (  .031)

                                                       -8                  30                .121
   4141             3836              5          ( -10,    -7)      (  30,     31)      (  .031)

                                                        0                  13                .356
   RTDM             3836              5          (   0,     1)      (  12,     13)      (  .031)

                                                       -4                  28                .301
   PLUMES           3836              5          (  -5,    -3)      (  28,     29)      (  .031)

                                                       -5                  26                .305
   COMPLEX/PFM      3836              5          (  -6,    -4)      (  26,     27)      (  .031)

                                                       -1                  23                .107
   SHORTZ           3836              5          (  -2,     0)      (  23,     24)      (  .031)

                                                        3                  12                .132
   IMPACT           3836              5          (   2,     3)      (  11,     12)      (  .031)

 * 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES
```

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
FOR THE 1-HOUR AVERAGING PERIOD
SUMMARY TABLE (PART 2)
CINDER CONE BUTTE (1980)

MODEL	FRACTION OF POSITIVE RESIDUALS (OBS>PRED)	ROOT MEAN SQUARE ERROR	AVERAGE ABSOLUTE RESIDUAL	PEARSON CORRELATION COEFFICIENT	SPEARMAN CORRELATION COEFFICIENT	VARIANCE COMPARISON* (OBS/PRED)
COMPLEXI	.49	21	11	.359	.333	.327 (.298, .356)
COMPLEXII	.56	35	13	.236	.391	.114 (.104, .125)
4141	.42	32	14	.277	.377	.143 (.130, .157)
RTDM	.47	13	5	.425	.409	1.035 (.940, 1.139)
PLUMES	.56	28	10	.223	.409	.175 (.156, .194)
COMPLEX/PFM	.55	27	11	.313	.353	.190 (.173, .219)
SHORTZ	.40	23	7	.236	.447	.251 (.238, .267)
IMPACT	.54	12	6	.299	.422	4.921 (4.179, 5.795)

* 95 PERCENT CONFIDENCE INTERVAL IN PARENTHESES

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                    COMPARISON OF ALL OBSERVED AND PREDICTED
                RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                          PAIRED IN TIME AND LOCATION
                           (FOR VARIOUS DATA SETS)
                               MODEL: COMPLEX1
                       FOR THE  1-HOUR AVERAGING PERIOD
                           CINDER CONE BUTTE (1980)
-------------------------------------------------------------------------------------------
        DATA SET              NUMBER        AVERAGE         AVERAGE         STANDARD
                                OF          OBSERVED       DIFFERENCE       DEVIATION
                              EVENTS         VALUE         (OBS-PRED)     OF RESIDUALS
-------------------------------------------------------------------------------------------
                                                               -6              20
        ALL                    3836            6

        BY RELEASE DISTANCE/
           RELEASE HEIGHT

          DISTANCE < 900. M                    8               -1              22
            H< 16. M            155            8               -7              24
            H=16. M TO 26. M    419                           -12              30
            H> 26. M            269           16

          DISTANCE > 900. M                                     2              13
            H< 16. M            308            6               -5              22
            H=16. M TO 26. M   1771            5               -6              13
            H> 26. M            914            3
-------------------------------------------------------------------------------------------

        METEOROLOGICAL CONDITION

        1. WIND SPEED                                          -8              24
            < 2.5 M/S          2272            6               -2              13
            2.5 TO 5. M/S      1033            5               -1               7
            > 5. M/S            531            3

        2. STABILITY GROUP                     6                1              15
            CLASS C+D          1247            5               -2              23
            CLASS E            1478            4               -9              21
            CLASS F            1111
```

247<

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEXII
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	4036	6	-5	34
BY RELEASE DISTANCE/ RELEASE HEIGHT				
DISTANCE < 900. M				
H< 15. M	155	6	-1	44
H=16. M TO 26. M	419	8	-5	26
H> 26. M	269	16	-15	56
DISTANCE > 900. M				
H< 16. M	508	6	2	19
H=16. M TO 26. M	1771	5	-7	38
H> 26. M	914	3	-6	21
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	2472	6	-9	42
2.5 TO 5. M/S	1033	5	-3	25
> 5. M/S	531	3	-1	11
2. STABILITY GROUP				
CLASS C+D	1447	3	1	19
CLASS E	1478	6	-10	45
CLASS F	1111	6	-9	39

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: COMPLEX/PFM
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3836	6	-5	25
BY RELEASE DISTANCE/ RELEASE HEIGHT				
DISTANCE < 900. M				
H< 16. M	155	6	-2	33
H=16. M TO 26. M	419	8	-5	25
H> 26. M	269	18	-14	53
DISTANCE > 900. M				
H< 16. M	308	8	2	15
H=16. M TO 26. M	1771	5	-6	26
H> 26. M	914	[illegible]	-3	12
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	2472	6	-8	32
2.5 TO 5. M/S	1033	[illegible]	[illegible]	12
> 5. M/S	331	[illegible]	1	9
2. STABILITY GROUP				
CLASS C+D	1247	6	1	16
CLASS E	1478	[illegible]	-8	29
CLASS F	1111	4	-7	30

249<

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                    COMPARISON OF ALL OBSERVED AND PREDICTED
               RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                         PAIRED IN TIME AND LOCATION
                           (FOR VARIOUS DATA SETS)
                                 MODEL: 4141
                      FOR THE  1-HOUR AVERAGING PERIOD
                          CINDER CONE BUTTE (1980)
--------------------------------------------------------------------------------------------
          DATA SET               NUMBER          AVERAGE          AVERAGE          STANDARD
                                   OF            OBSERVED        DIFFERENCE        DEVIATION
                                 EVENTS           VALUE          (OBS-PRED)      OF RESIDUALS
--------------------------------------------------------------------------------------------

          ALL                     2636              6               -8                30

          BY RELEASE DISTANCE/
             RELEASE HEIGHT

            DISTANCE < 900. M
              H< 16. M             155              8               -2                29
              H=16. M TO 26. M     419              6               -9                29
              H> 26. M             267             16              -25                52

            DISTANCE > 900. M
              H< 16. M             368              8                0                17
              H=16. M TO 26. M    1771              5               -9                33
              H> 26. M             914              5               -7                17
--------------------------------------------------------------------------------------------

          METEOROLOGICAL CONDITION

          1. WIND SPEED
              < 2.5 M/S           2272              6              -12                37
              2.5 TO 5. M/S       1233              5               -3                17
              > 5. M/S             551              5               -3                11

          2. STABILITY GROUP
              CLASS C+D           1247              8                0                15
              CLASS E             1479              6              -11                30
              CLASS F             1111              4              -14                40
```

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: PLUMES
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3836	6	-4	28
BY RELEASE DISTANCE/ RELEASE HEIGHT				
DISTANCE < 900. M				
H< 16. M	155	8	-1	33
H=16. M TO 26. M	419	5	-5	26
H> 26. M	269	16	-1	32
DISTANCE > 900. M				
H< 16. M	308	8	2	17
H=16. M TO 26. M	1771	5	-5	32
H> 26. M	914	7	-4	13
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	2272	6	-5	33
2.5 TO 5. M/S	1033	5	-2	20
> 5. M/S	531	5	-1	11
2. STABILITY GROUP				
CLASS C+D	1247	8	-1	22
CLASS E	1478	6	-7	38
CLASS F	1111	4	-3	18

```
                 COMPARISON OF ALL OBSERVED AND PREDICTED
             RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
                      PAIRED IN TIME AND LOCATION
                         (FOR VARIOUS DATA SETS)
                              MODEL: RTDM
                   FOR THE  1-HOUR AVERAGING PERIOD
                        CINDER CONE BUTTE (1980)
--------------------------------------------------------------------------------------------------
     DATA SET                   NUMBER           AVERAGE          AVERAGE          STANDARD
                                  OF             OBSERVED        DIFFERENCE        DEVIATION
                                EVENTS            VALUE          (OBS-PRED)       OF RESIDUALS
--------------------------------------------------------------------------------------------------

     ALL                         4036               5                0                13

     BY RELEASE DISTANCE/
        RELEASE HEIGHT

      DISTANCE < 900. M
        H< 16. M                  155               8                5                15
        H=16. M TO 26. M          419               5               -1                15
        H> 26. M                  269              15               -4                32

      DISTANCE > 900. M
        H< 16. M                  508               6                5                13
        H=16. M TO 26. M         1771               5                1                 9
        H> 26. M                  914               7               -2                 9
--------------------------------------------------------------------------------------------------

     METEOROLOGICAL CONDITION

     1. WIND SPEED
          < 2.5 M/S              1472               6               -1                15
          2.5 TO 5. M/S          1632               5                1                 9
          > 5. M/S                931               6                1                 7

     2. STABILITY GROUP
          CLASS C+D              1247               6                2                13
          CLASS E                1478               5                0                12
          CLASS F                1111               4               -2                13
```

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES ((10**(-6)) S/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: SHORTZ
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	3836	6	-1	23
BY RELEASE DISTANCE/ RELEASE HEIGHT				
DISTANCE < 900. M				
H< 16. M	155	8	4	15
H=16. M TO 26. M	419	6	-1	16
H> 26. M	269	15	-13	59
DISTANCE > 900. M				
H< 16. M	506	6	5	13
H=16. M TO 26. M	1771	5	1	9
H> 26. M	914	7	-5	33
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	2272	6	-1	19
2.5 TO 5. M/S	1033	7	-1	16
> 5. M/S	531	8	-1	43
2. STABILITY GROUP				
CLASS C+D	1247	6	2	14
CLASS E	1478	6	-1	19
CLASS F	1111	4	-4	36

COMPARISON OF ALL OBSERVED AND PREDICTED
RELATIVE CONCENTRATION VALUES (10**(-6) S/M**3)
PAIRED IN TIME AND LOCATION
(FOR VARIOUS DATA SETS)
MODEL: IMPACT
FOR THE 1-HOUR AVERAGING PERIOD
CINDER CONE BUTTE (1980)

DATA SET	NUMBER OF EVENTS	AVERAGE OBSERVED VALUE	AVERAGE DIFFERENCE (OBS-PRED)	STANDARD DEVIATION OF RESIDUALS
ALL	[illegible]036	6	3	12
BY RELEASE DISTANCE/ RELEASE HEIGHT				
DISTANCE < 930. M				
H< 16. M	155	6	7	15
H=16. M TO 26. M	419	8	2	12
H> 26. M	268	10	10	23
DISTANCE > 930. M				
H< 15. M	568	4	7	12
H=16. M TO 26. M	1771	5	3	10
H> 26. M	314	3	0	5
METEOROLOGICAL CONDITION				
1. WIND SPEED				
< 2.5 M/S	[illegible]272	6	3	13
2.5 TO 5. M/S	1[illegible]33	5	3	10
> 5. M/S	531	4	3	5
2. STABILITY GROUP				
CLASS C+D	1297	6	5	13
CLASS E	1478	5	2	11
CLASS F	1[illegible]11	4	2	1[illegible]